Clean and lean

Battery metals demand from electrifying passenger transport

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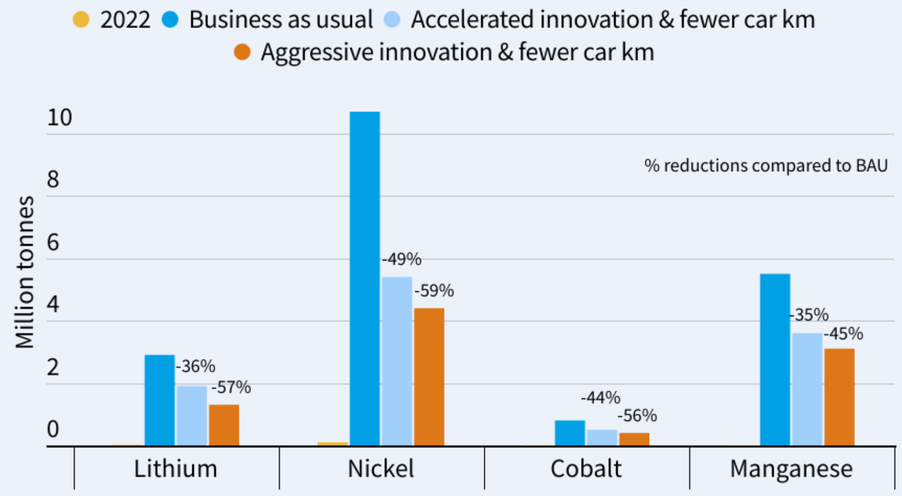
Executive Summary

Europe, like many other regions, is accelerating efforts to electrify cars, buses and coaches in order to decarbonise passenger transport effectively and reach its climate goals. Electrification at speed and scale is essential, with all new cars, buses and coaches having to be zero emission by 2035 latest. But batteries - just like renewables and technologies relying on green hydrogen - will require metals like lithium and nickel to produce. What are the volumes of these metals that are required to electrify European passenger transport? And how do choices - be it the size of cars, the technology used or the size of the car fleet - impact demand? This report answers those questions.

T&E has developed three scenarios for the demand of battery raw materials, notably lithium, nickel, cobalt and manganese, between today and 2050. All of the scenarios assume full electrification of passenger transport by 2050 and an accelerated uptake of battery electric vehicles up to then to maximise the CO_2 savings from now on. The “Business as Usual” - *BaU* - scenario takes the currently expected industry trends on battery size and chemistry, as well as the status quo private car activity. The “Accelerated Innovation and Fewer Car Km” - or *Accelerated* - scenario assumes a substantial shift to smaller batteries, a faster uptake of battery chemistries with less critical metals (e.g. lithium batteries without cobalt or nickel (LFP), or sodium-ion batteries) and and fewer km driven by private car. The final “Aggressive Innovation and Fewer Car Km” - or *Aggressive* - scenario takes these assumptions up another notch to more radical changes.

Demand for battery metals grows in all scenarios, but can be almost halved with innovative technology and car use policy

The demand for raw materials increases in all the three scenarios, with annual volumes in 2050 estimated to be 4 to 10 times higher than today, and cumulatively up to 200 times higher than the 2022 EV battery industry consumption. While this translates into 20 Mt of lithium, nickel, cobalt and manganese, it is well below the current annual oil consumption of around 170 Mtoe (expected to fall to around 20 Mtoe by 2050).



Source: T&E analysis

27 TWh of batteries will be needed cumulatively until 2050 in BAU, equivalent to 2.9 million tonnes (Mt) of lithium, 10.7 Mt of nickel, 0.8 Mt of cobalt and 5.5 Mt of manganese. This European demand represents up to 11% of the known global reserves for lithium and nickel, 10% for cobalt and 1% for manganese.

The Accelerated scenario would require a total of 19 TWh of batteries, or a third less. This means that compared to the BaU scenario, the raw material requirements are:

- 1.9 Mt of lithium, or over a third less
- 5.4 Mt of nickel, or around half
- 0.5 Mt of cobalt, or 44% less
- 3.6 Mt of manganese, or over a third less.

The Aggressive scenario would require nearly half the amount of batteries cumulatively by 2050 compared to the BAU scenario, resulting in an even larger decrease in the demand of critical metals: 57% less lithium, 59% less nickel, 56% less cobalt and 45% less manganese.

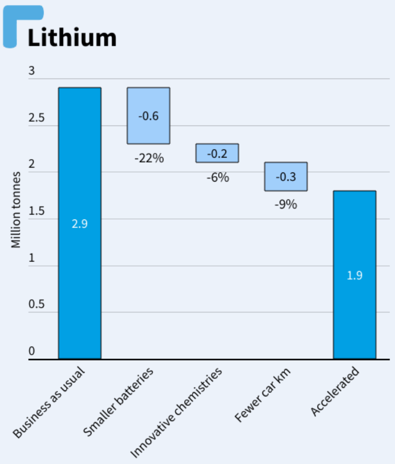
This shows that the essential electrification of passenger transport will require a growing supply of critical metals in all scenarios. While globally there are enough reserves for the EU needs, the challenge is to extract and process those at speed, and above all in a social and environmentally responsible manner. But not all supply needs to come from extraction: a growing share (up to 15%) of the supply can be met by recycled metals by 2030 already, so industrial support to scale secondary metals production in Europe is critical. Ultimately, what the analysis shows is that the demand for metals can be seriously tempered depending on the transport demand scenario.

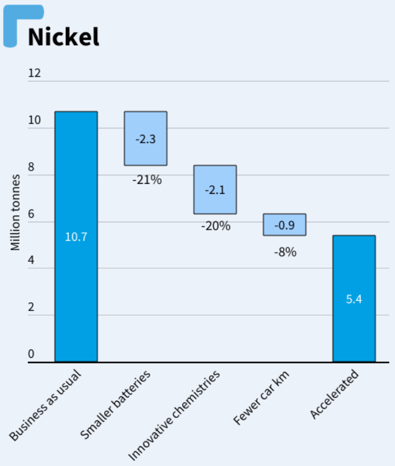
Smaller batteries are key to reduce demand for raw materials

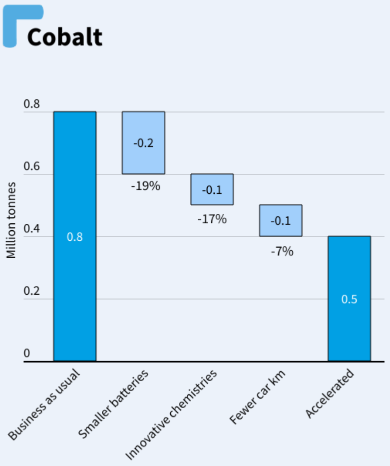
T&E also analysed the relative contribution of the different factors - smaller batteries (either via smaller efficient cars, which also leads to less steel and aluminium demand, or simply shorter ranges), innovative chemistries and measures to reduce car travel - on the demand for battery raw materials.

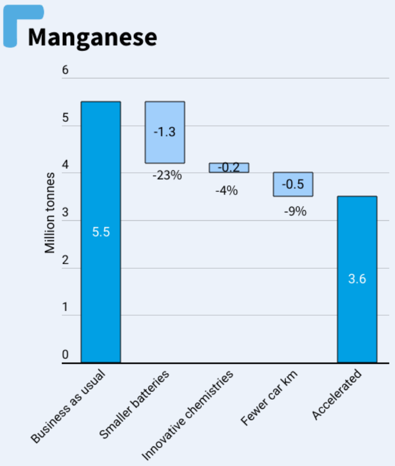
The results show that both technological (battery size and chemistry) and car usage factors have an equally important impact on the demand. Smaller batteries represent the single factor bringing the largest impact, 19%-27% reduction in raw materials cumulatively across the Accelerated and Aggressive scenarios.

In the Accelerated scenario, shifting to smaller batteries results in a 19%-23% reduction in the raw materials demand. Switching to less resource intensive chemistries brings an additional 4-20% reduction. Reducing the km driven by private cars is responsible for 7%-9% of the reduction.









In the Aggressive scenario, the more radical measures around car usage bring in around a fifth of raw materials demand reduction compared to BAU, while smaller batteries are responsible for around a quarter, with innovative chemistries 10%-15% (except for manganese where demand increases as it replaces nickel-rich chemistries used today).

The single largest factor responsible for reducing battery metal demand is achieved by shifting to smaller batteries. This can be done by either downsizing electric vehicles themselves or by simply shifting to smaller batteries with less range while keeping the car size constant. Overall, including materials like steel and aluminium, downsizing vehicles is the best strategy not just for resource use, but also from the social (=affordability) and industrial (=large volumes globally) point of view. In a supply constrained world, this is also sound economic and industrial policy. But it requires a strategy to push European automakers to manufacture more entry-level smaller models given the dominance of large e-models on the European market today.

Smaller electric cars, being lighter, would be ideal for less resource intensive chemistries, notably sodium-ion, while guaranteeing sufficient range. But while first models with this chemistry are being sold in China from 2023 (e.g. the BYD Seagull), no commercial plans exist in Europe. It is critical European companies move into this space fast.

Policies are key to make this happen

Without strong measures, automakers will continue marketing and selling larger and heavier electric cars in pursuit of profit. Awareness campaigns on their own will not be enough to convince people to drive their private cars less or switch to a bike. Strong policy at European, national and - crucially - local level is key to ensure the essential transition to electrification happens in the most resource efficient manner.

An EU-wide strategy is needed to shift to smaller, affordable and resource light electric vehicles, including tax incentives, European battery efficiency standards and incentives on automakers to produce more entry-level models. On top of already strong research & development policy across Europe, strong industrial policy is needed to commercialise new, less resource intensive chemistries. Notably, scaling up European production of iron-based (LFP) and sodium-based (Na-ion) batteries.

Reducing the km driven in private cars will require a range of measures. These start with reducing road building and the space available for private cars via spatial planning (e.g. making essential facilities available in every district, creating pedestrianised areas or redirecting through-traffic) and parking charges. Improving public transport and infrastructure for active modes (e.g. biking lanes and hangars, school streets) as well as incentives to promote shared mobility (car and ride sharing, bike and e-scooter sharing) are also important.

Electrifying passenger transport is essential for the climate, but it doesn't have to break the planet. Ensuring metals are responsibly sourced and recovered from old products as much as possible, while putting in place measures to downsize cars and change the way we move will make the transformation truly sustainable and resource savvy.

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Acronyms

BAU - Business as Usual scenario
BEV - battery electric vehicle
Co - cobalt
CLTC - China Light Duty Vehicle Test Cycle
CRM - critical raw materials
DRC - Democratic Republic of the Congo
EV - electric vehicle
FCEV - fuel cell electric vehicle
GWh - gigawatt-hour
IRMA - The Initiative for Responsible Mining Assurance
kt - kilotonnes
kWh - kilowatt-hour
Li - lithium
Li-ion batteries - lithium-ion batteries
LFP - lithium iron phosphate
LMFP - lithium manganese iron phosphate
LMR-NMC - lithium-manganese rich nickel manganese cobalt oxide
LNMO - lithium nickel manganese oxide
Mn - manganese
Mt - million tonnes
Mtoe - million tonnes of oil equivalent
Na-ion batteries - sodium-ion batteries
Ni - nickel
NCA - lithium nickel cobalt aluminium oxide
NMC - lithium nickel manganese cobalt oxide
SUV - sport utility vehicle
USGS - US Geological Survey
ZEV - zero emissions vehicle

1. Introduction

Transport decarbonisation and electrification is a crucial component of the European Green Deal. Electrifying passenger transport is essential if Europe is to meet its climate and air quality targets and should happen at a much faster speed and scale than today. But technologies such as batteries will require large amounts of raw materials such as nickel, lithium, cobalt and manganese. In the Sustainable Policy Scenario developed by the International Energy Agency, mineral demand could grow by 30 times between 2020 and 2040 globally [1]. The concerns of such high projections are two-fold: on the one hand, insufficient raw materials supply can lead to market volatility and slowdown the transition to a net-zero economy; on the other hand, mining expansion, without appropriate regulatory safeguards in place, can pose environmental and social risks.

Alongside stronger regulation on the mining sector, it is important to also take measures to reduce reliance on primary production via various levers: decrease raw materials intensity in batteries through optimised battery sizes and diversified battery chemistries, and at the same time decrease private car dependency and increase public and active transport usage.

In this report T&E aims at estimating the amount of battery grade nickel, lithium, cobalt and manganese needed to decarbonise passenger transport in three scenarios in Europe, and explores how different approaches to battery size, battery chemistry and car usage influence this demand. A future of zero-emissions transportation will require some level of mining in all scenarios, this is why strict environmental and social standards are essential to ensure a fair and equitable transition.

2. Decarbonised transport scenarios

The starting point of this analysis is that cars, buses and coaches all electrify based on the most ambitious timeline feasible that is in line with Europe's 2050 zero emissions goal, and the global Paris agreement. This means all new cars are modelled to be electric by 2032, buses by 2027 and coaches by 2035. The necessary electrification uptake is modelled to achieve the 100% zero emissions effectively, same across all scenarios.

Sales of new cars are assumed to reach a 24% electrification rate in 2025, 80% in 2030 and 100% in 2032 and beyond. These assumptions are more ambitious than the European Commission proposals and are part of the T&E scenario that implies a faster electrification of corporate fleets and increased ambition of the car CO2 standards. The share of electric buses in total new bus sales would increase from 23% in 2025 to 100% in 2027 and thereafter, while electric coaches would account for 3% of total coach sales in 2025, growing to 64% in 2030 and 100% by 2035.

Finally, considering the complete electrification in all scenarios, it is assumed that a sufficient number of charging stations will be available to allow fast electrification and smaller batteries. Upcoming regulations (e.g. Alternative Fuel Infrastructure Regulation - AFIR) will require governments to invest and develop the necessary infrastructure.

Share of electric	**2025**	**2030**	**2035 on**
Cars	24%	80%	100%
Buses (100% in 2027)	23%	100%	100%
Coaches (battery & fuel cell)	3%	64%	100%

Table 1: Electrification uptake by vehicle segment

T&E developed three potential future scenarios for selected battery cathode raw materials demand in passenger transport based on several factors in order to compare the consumption of lithium, nickel, cobalt and manganese - which are today a focus of T&E's work. The factors are:

- battery capacity or size;
- battery chemistry;
- passenger distance travelled by transport mode (private car km vs. public transport).

The analysis focuses on Europe (the EU, the UK, Norway and Switzerland) and covers the period from 2022 to 2050. A variety of data sources ranging from in-house models and expertise to estimates based on third party sources such as BloombergNEF, LMC Automotive and TNO was used [2–4]. More details on the methodology can be found in the Annex.

Finally, the report acknowledges that apart from the cathode-focused raw materials, the electrification of the passenger transport will require many of other minerals used in other electric vehicle components, such as graphite for battery anodes; rare earth elements (REEs) for some electric engine technologies; copper for current collectors, wirings and motor coils; and aluminium for current collectors, casings and vehicle body components, which are not within the scope of this report. Materials for broader infrastructure demand, such as charging, is also excluded.

Scenario 1: Business as usual

In this scenario, passenger transport activity (or distance travelled) is aligned with the EU Reference Scenario 2020 [5], which projects energy, transport and greenhouse gas emissions trends to 2050 for the EU member states. These scenarios imply no meaningful modal shift in the long run, with passenger cars maintaining a high share in transport activity mix (~88%) in 2050.

With regards to battery capacities (or battery sizes), these were assumed to follow the industry's trend towards larger size batteries based on LMC Automotive data available until 2030, i.e. 73 kWh in 2030 and beyond. At the same time electric buses and coaches will see a declining trend in battery capacities as their energy efficiency improves (from 281 kWh today to 252 kWh in 2050 for buses, and from 777 kWh today to 616 kWh in 2050 for battery electric coaches; batteries of the fuel cell coaches are presumed to stay constant at 140 kWh throughout the period). These figures are based on TNO data for long haul trucks with a 500 km range, given the similarities between coaches and trucks in terms of battery range and chemistries and lack of additional data on coaches [4].

The battery chemistry mix for cars in this scenario is made up of mainly of iron-based, cobalt- and nickel-free (LFP, LFMP) and nickel-rich chemistries as is the case today (NMC, NCA variations, also known as ternary chemistries), in addition to some manganese-based formulations (LMR-NMC, LNMO). Considering the recent advances in sodium-ion (Na-ion) batteries, a small share of these to the chemistry mix was added, achieving a market penetration rate of up to 10% by 2050 and finding application in the small car segment. This can be justified in the Business as Usual (BaU) because, according to BNEF, by 2025 sodium-ion batteries are expected to achieve a comparable energy density to LFP's density in the early 2020s when LFP grew its global market share [6]. For chemistry abbreviations please see the Acronyms section.

Buses would use a large share of iron-based chemistries, along with manganese-rich chemistries. Coaches, which need more driving autonomy than buses, will be dominated by nickel-rich and manganese-rich chemistries. Sodium-ion batteries do not make a big contribution here in this scenario, instead more resource intensive technologies as today are used.

The long term estimated projections for the battery chemistry mix is estimated based on BloombergNEF data available until 2035 and Benchmark Mineral Intelligence data on sodium-ion batteries [7, 8].

Scenario 2: Accelerated innovation and fewer car km scenario

With an assumption of stricter urban planning and car use measures in place (for example distance based charges, congestion charges, parking pricing and speed limits), passenger distance travelled by car is modelled to decrease by 5% in 2030 and 10% in 2040 compared to BaU. The lower distance travelled is accompanied by a shift from passenger cars to public transit and active mobility: 6% during the 2030s and 12% of travel by car during 2040-2050 shifted to other modes, in comparison to BaU. Around half of this shift would be allocated towards electric buses and coaches for urban travel, while the other half would be directed towards suburban trains (which are not covered in this report). Additionally, it was assumed that the passenger car occupancy would increase by 5% during the 2030s and by 10% during 2040-2050 compared to BaU.

This reduction in car km driven would result in lower car and van sales and higher bus and coach sales and activity relative to BaU.

Weight-based vehicle taxation measures and robust industrial policies would shift the focus from larger batteries to more efficient and optimised battery designs and contribute to the adoption of lower battery capacities in cars, i.e. from an average 68 kWh in 2025 to 50 kWh by 2050. People would opt for compact cars rather than oversized, unsustainable and pricey cars (such as sport utility vehicles, SUVs).

Capacities of electric bus batteries would slightly increase to 300 kWh in 2050 in light of more intense usage as people shift from cars. Battery sizes of coaches are considered to be the same as in BaU due to lack of data and uncertainty as to how the segment would develop in the future.

In this scenario a more forward looking uptake of battery chemistries was assumed, especially for lower critical metals types in this scenario. Battery chemistries of cars comprise a higher share of chemistries without nickel or cobalt which pose supply bottlenecks and sustainability challenges such as iron-based LFP and iron-based with manganese addition LFMP as well as emerging but promising technologies such as sodium-ion batteries, which will soon be commercialised in China. The recently unveiled Seagull model by Chinese carmaker BYD will have a 30 kWh sodium-ion battery and a CLTC (China Light Duty Vehicle Test Cycle)[1] range of 306 km in one charge, while Sehol EX10 made by Volkswagen's joint venture with JAC, also in China, has a 25 kWh battery pack for a 252 km range [9, 10]. The low cost sodium-ion batteries would make cars affordable to cost conscious consumers and, topped with social leasing policies, ensure social equity in transportation, hence in this scenario it is assumed a share of 20% by 2050 in cars.

Considering that there are several types of sodium-ion batteries and it is uncertain which one will prevail in the future, it is assumed that half of the volumes will be layered oxide sodium-ion (containing critical raw materials such as manganese and lithium) and the other half Prussian White sodium-ion without critical raw materials (which includes elements such as iron, among others).

INFO BOX: Sodium-ion batteries

Sodium-ion batteries represent a viable alternative to lithium-ion batteries due to sodium’s low cost and abundance as the sixth most common element on Earth [11]. Sodium-ion batteries are non-flammable (thus safer), have longer cycle life, perform well in low temperatures and can be more sustainable due to their reduced use of critical materials [6, 12]. The main drawback today is their relatively lower energy density compared to lithium-ion batteries, meaning the same mass battery pack provides shorter driving ranges, but ongoing research & development aims at improving their performance which is expected to have energy densities similar to LFP batteries at lower cost once the production is scaled up.

Sodium-ion batteries come in several formulations. Layered metal oxides are a similar structure to the lithium NMC, however, producers tend to avoid cobalt and minimise nickel content [13]. Prussian Blue Analogues (PBAs) represent the lowest cost sodium-ion battery alternative as they contain mainly sodium and iron, while the so-called polyanionic formulation would be more suitable for power tool applications.

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[1] CLTC ranges tend to be 25%-30% lower than real world ranges.

Since electric buses will need to drive longer distances due to higher usage and network coverage, some nickel-rich and manganese-rich chemistries will continue being used in this segment, although overall iron-based would be prevalent. Coaches too will need more driving autonomy, therefore a mix of iron-based, nickel-rich and manganese-rich chemistries would be used with a small share for sodium-ion batteries.

Scenario 3: Aggressive innovation and fewer car km scenario

This scenario proposes the most aggressive assumptions around passenger distance travelled, battery sizes and novel battery chemistries that would reduce the social and environmental burden associated with mineral extraction. Achieving these targets, notably on the amount of km driven by cars, would require radical policies, including bans and scrappage of private cars to ensure less private car travel. On the technology side, we will need not just investments in research and development, but a huge focus on scaling the new chemistries fast and developing new supply chains quickly.

Strict city planning policies and radical measures on car usage are key in this scenario. As a result of those, is it assumed that passenger distance travelled would decline by 15% during the 2030s and by 25% during 2040-2050 compared to BaU. This is accompanied by a shift from cars to other other transport modes of 15% during the 2030s and some 30% during 2040-2050, half of which would be directed to buses and coaches (and the other half other modes, e.g. railway, cycling, walking). The car occupancy would increase by 10% during the 2030s and by 25% during 2040-2050, resulting in an occupancy rate of 2.5 passengers per car compared to just 2.0 in BaU.

The electric vehicle shares compared to total vehicle sales remain the same as in the previous scenarios (with battery electric cars reaching 100% of sales in 2032), but the car km travelled assumptions above would result in overall lower electric car sales and higher electric bus and coach sales than in the previous scenarios.

Measures such as taxing vehicle weight and adapted industrial policy on carmakers (e.g. low cost leasing) would shift the focus from larger car batteries to small ones even more in this scenario than in the Accelerated scenario. Cars would be adapted for smaller ranges but sufficient for everyday commutes and urban driving, with average battery capacities declining from 68 kWh in 2025 to 40 kWh by 2050.

At the same time, the average battery capacity of electric buses would be somewhat higher than in the BaU scenario in order to accommodate increased usage of public transportation (but same as in the Accelerated scenario, i.e. 300 kWh by 2040). The same capacities are maintained for coaches as in the previous scenarios due to lack of data (616 kWh by 2050 for battery electric coaches and 140 kWh for fuel cell coaches).

In terms of battery chemistries, this scenario goes even further than the previous one and assumes promising innovative solutions that are less intensive in critical raw materials, such as sodium-ion, being prevalent in electric cars (40% share by 2050). In addition, iron-based chemistries and some nickel-based and manganese-based chemistries will continue to be used for longer ranges.

Electric buses will be dominated by iron-based chemistries along with sodium-ion and some nickel-based and manganese-based formulations. Coaches will rely on iron-based primarily, and to a lesser extent on nickel-rich, manganese-rich and some sodium-ion batteries.

Summary of scenarios

Table 2 summarises the key inputs of the scenarios considered in this report.

Factors	**Business as usual (BAU)**	**Accelerated scenario**	**Aggressive scenario**
Description	Scenario follows the current status quo of the industry trends on technology and transport activity	Scenario involves optimised batteries and chemistry technologies as well as lower car activity	Most radical scenario entailing drastic technology changes and lower car activity
Distance travelled (transport activity)	Default (EU Reference Scenario)	-5% in 2030s compared to BAU -10% in 2040-2050	-15% in 2030s compared to BAU -25% in 2040-2050
Fewer car km - modal shift	Default	6% in 2030s compared to BAU 12% in 2040-2050 (50% of shift to go to buses)	15% in 2030s compared to BAU 30% in 2040-2050 (50% of shift to go to buses)
Fewer car km - car occupancy	Default	5% in 2030s 10% in 2040-2050	10% in 2030s 25% in 2040-2050
ZEV uptake - cars	Accelerated T&E scenario 80% in 2030 100% in 2035		
ZEV uptake - buses & coaches	T&E scenario 100% in 2027 for buses 100% in 2035 for coaches		
Average battery sizes - cars	70 kWh 2025 74 kWh after 2035	68 kWh 2025 50 kWh by 2050	68 kWh 2025 40 kWh by 2050

Factors	Business as usual (BAU)	Accelerated scenario	Aggressive scenario
Average battery sizes - buses & coaches	Buses: 281 kWh in 2025 & declining to 252 kWh Coaches: 777 kWh BEV & declining to 616 kWh, 140 kWh FCEV constant	Buses: 281 kWh in 2025 & increasing to 300 kWh Coaches: 777 kWh BEV & declining to 616 kWh, 140 kWh FCEV constant	Buses: 281 kWh in 2025 & increasing to 300 kWh Coaches: 777 kWh BEV & declining to 616 kWh, 140 kWh FCEV constant
Chemistries	T&E estimated based on BNEF data.	T&E estimates	T&E estimates
Chemistries 2050 - cars	Ni-rich: 25% Mn-rich: 20% Fe-based: 45% Sodium-ion (Na-ion): 10%	Ni-rich: 15% Mn-rich: 10% Fe-based: 55% Na-ion: 20%	Ni-rich: 10% Mn-rich: 10% Fe-based: 40% Na-ion: 40%
Chemistries 2050 - buses	Ni-rich: 10% Mn-rich: 25% Fe-based: 55% Na-ion: 10%	Ni-rich: 10% Mn-rich: 15% Fe-based: 55% Na-ion: 20%	Ni-rich: 8% Mn-rich: 10% Fe-based: 57% Na-ion: 25%
Chemistries 2050 - coaches	Ni-rich: 40% Mn-rich: 50% Fe-based: 10% Na-ion: 0%	Ni-rich: 25% Mn-rich: 25% Fe-based: 40% Na-ion: 10%	Ni-rich: 20% Mn-rich: 20% Fe-based: 45% Na-ion: 15%

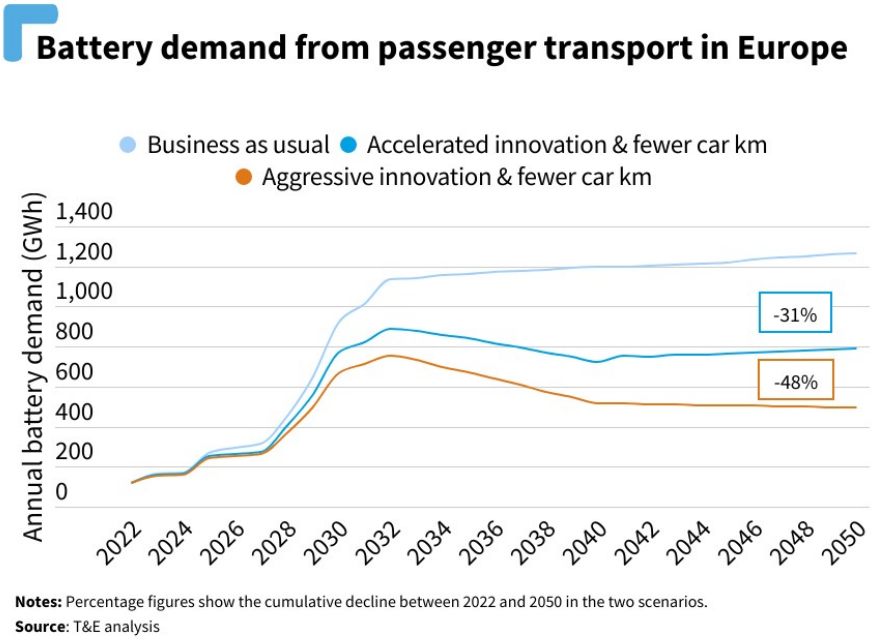
Table 2: Summary of scenario assumptions

3. Results

3.1 How much battery raw materials will Europe need for the EV transition?

The Business as Usual scenario, which maintains the current projections for passenger distance travelled as well as the prevailing industry trends in battery technologies, is estimated to require up up 1.3 TWh of batteries per year by 2050, and 27 TWh cumulatively between 2022 and 2050. In comparison, the proposed alternative scenarios, which imply technological changes as well as fewer car km driven overall, would require significantly less batteries: 38% less batteries in 2050 and 31% less batteries cumulatively until 2050 in the Accelerated Innovation & Fewer Car Km scenario; and around 60% less batteries in 2050 and 48% less cumulatively in the Aggressive Innovation & Fewer Car Km scenario respectively (Fig. 1).

The demand would continuously grow until 2050 in BaU scenario, while in the Accelerated and Aggressive scenarios it would peak in the 2030s driven by fleet electrification and decline thereafter due to the optimization of technology and improvements in vehicle usage patterns.



Notes: Percentage figures show the cumulative decline between 2022 and 2050 in the two scenarios.
Source: T&E analysis

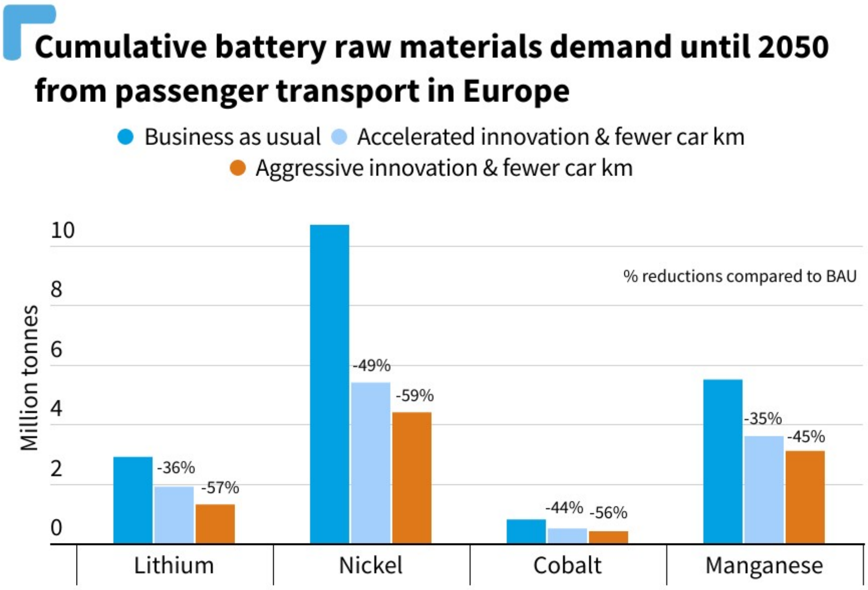
Figure 1: Battery demand from passenger transport in Europe

When looking at the raw materials required for these batteries, the analysis shows that the BaU approach will require the following quantities of raw materials for batteries in the year 2050: 8 times more lithium, 5 times more nickel, twice more cobalt and 22 times more manganese than in 2022 (see Annex 6.2). On a cumulative basis the transition would require: 2.9 million tonnes (Mt) of lithium (compared to 15 kt in 2022), 10.7 Mt of nickel (vs. 70 kt), 0.8 Mt of cobalt (vs. around 15 kt) and 5.5 Mt manganese (vs. 15 kt) (Fig. 2).

In the Accelerated scenario, which envisages smaller batteries, innovative chemistries and fewer km travelled by private vehicles, the annual consumption of raw materials would grow moderately. Europe would need in 2050: 5 times more lithium than today, more than twice more nickel, similar amounts of cobalt and 12 times more manganese than today. Cumulatively, these volumes would account for: 1.9 Mt of lithium, 5.4 Mt of nickel, 0.5 Mt of cobalt and 3.6 Mt of manganese, which is 35% to 49% lower than in BaU depending on the metal.

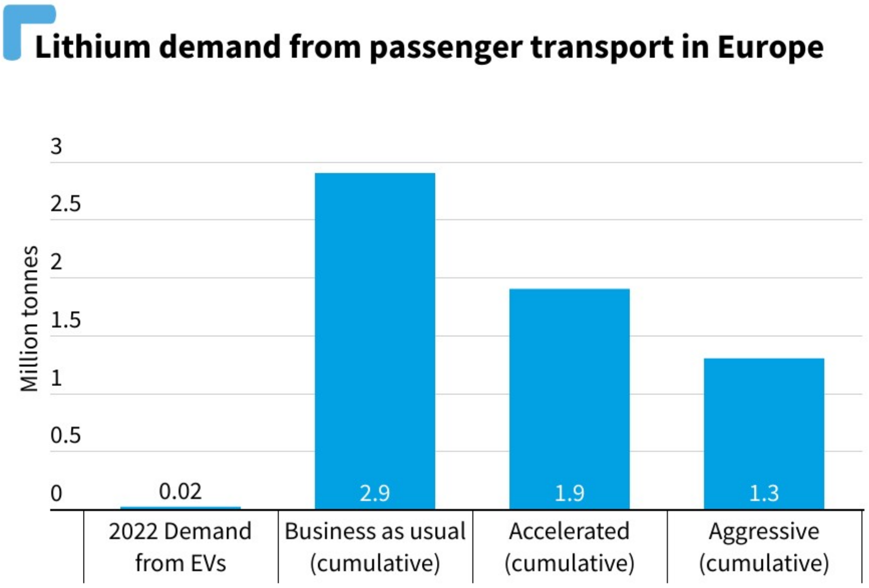
The Aggressive scenario with a more radical shift away from cars and towards small batteries and unconventional chemistries would see passenger transportation intake of raw materials increase slower. Compared to 2022 the amounts needed in 2050 will be double for lithium, 60% higher for nickel, almost half for cobalt and 10 times higher for manganese. Cumulatively, Europe would need 1.3 Mt of lithium, 4.4 Mt of nickel, 0.4 Mt of cobalt, and 3.1 Mt of manganese between 2022 and 2050. This scenario would see the volume reduction ranging from 45% to 59% compared to BAU.

The demand for raw materials by scenario on an annual basis (for the years 2022, 2030, 2040 and 2050) is shown in Annex 6.2 of the report.



Source: T&E analysis

Figure 2: Cumulative battery raw materials demand until 2050 from passenger transport in Europe



Source: T&E analysis

Figure 3: Lithium demand from passenger transport in Europe (2022 vs cumulative across the scenarios)

With more optimised batteries and fewer car km driven, demand for lithium in the Accelerated scenario can be lowered by 36% (Fig. 3). If a more aggressive approach would be taken, the demand could be reduced by more than half. Shifting from lithium-ion batteries to sodium-ion batteries, which are free of lithium, would alleviate some of the pressure on the lithium market. The volatile price dynamics of lithium of the past several years have accelerated the commercialisation of lithium-free batteries such as sodium-ion batteries, which can alleviate supply bottlenecks in the lithium market.

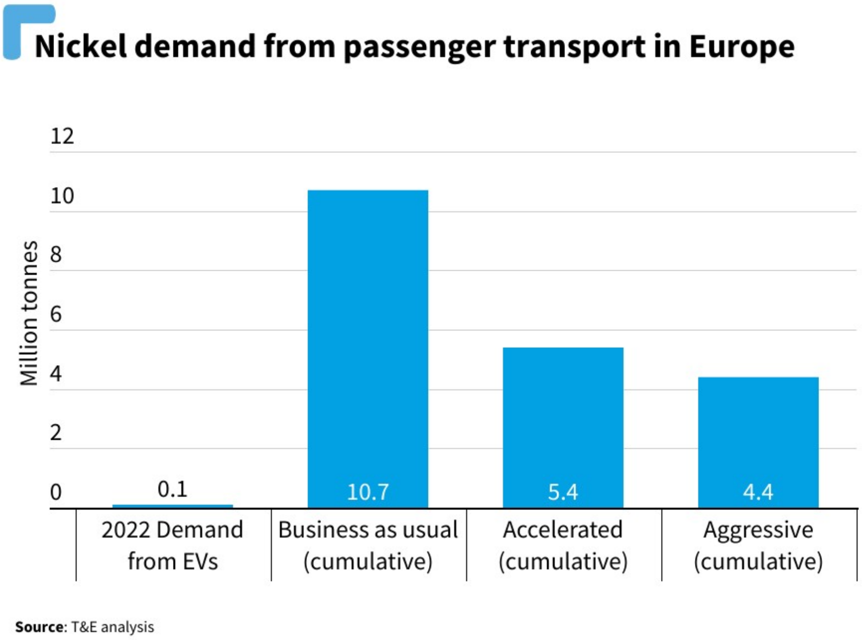


Figure 4: Nickel demand from passenger transport in Europe (2022 vs cumulative across the scenarios)

If the sector continues to maintain the status quo, nickel will be the most demanded metal among the four analysed here, in absolute terms (Fig. 4). Nickel in batteries provides higher energy density, meaning longer driving ranges, which makes NMC (lithium nickel-manganese-cobalt oxide) and NCA (lithium nickel-cobalt aluminium-oxide) the preferred chemistry for cars today outside China [1]. Although some level of nickel will be needed for longer transport routes, the alternative scenarios propose future pathways that decrease the consumption of nickel in vehicles by 49% and 59%, respectively.

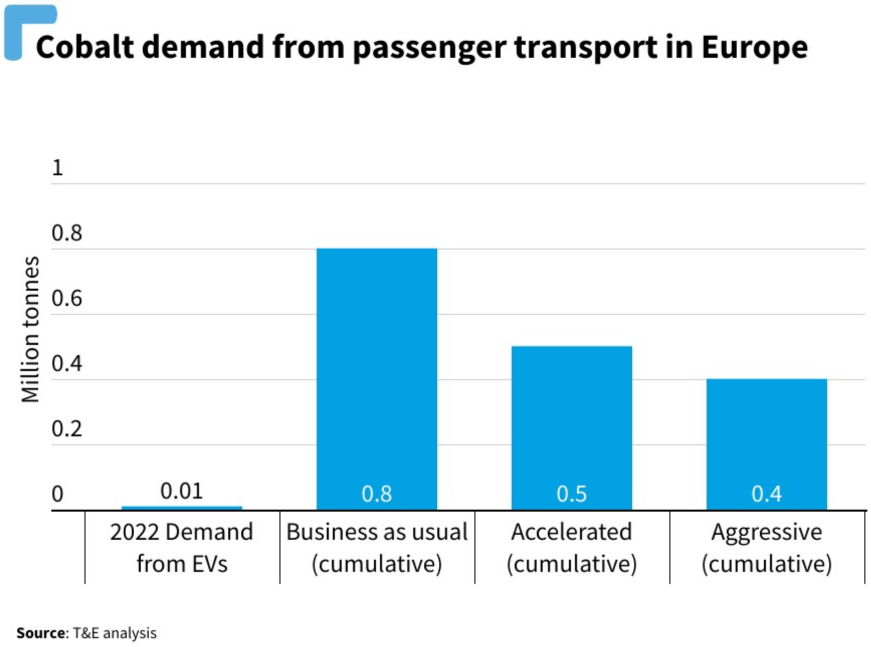
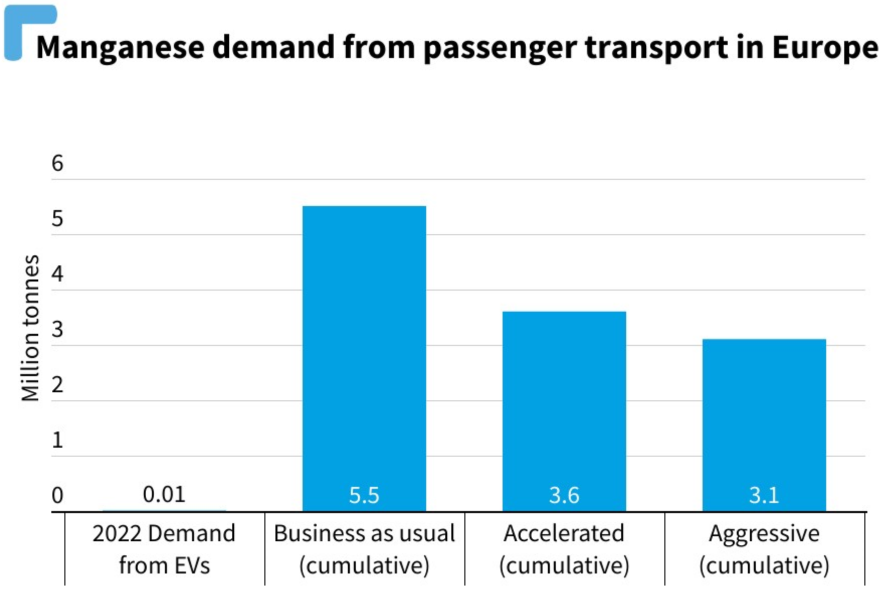


Figure 5: Cobalt demand from passenger transport in Europe (2022 vs cumulative across the scenarios)

Cobalt in batteries provides enhanced thermal safety and energy density, but due to past market price volatility and social concerns related to mining practices in the Democratic Republic of the Congo (DRC), it has been increasingly engineered out of batteries (especially in NMC chemistries, in favour of higher nickel content). More can be substituted in the Accelerated and Aggressive scenarios, i.e. 44% and 56%, respectively (Fig. 5). It must be noted that global initiatives are underway to foster ethical standards in the cobalt supply chain.



Source: T&E analysis

Figure 6: Manganese demand from passenger transport in Europe (2022 vs cumulative across the scenarios)

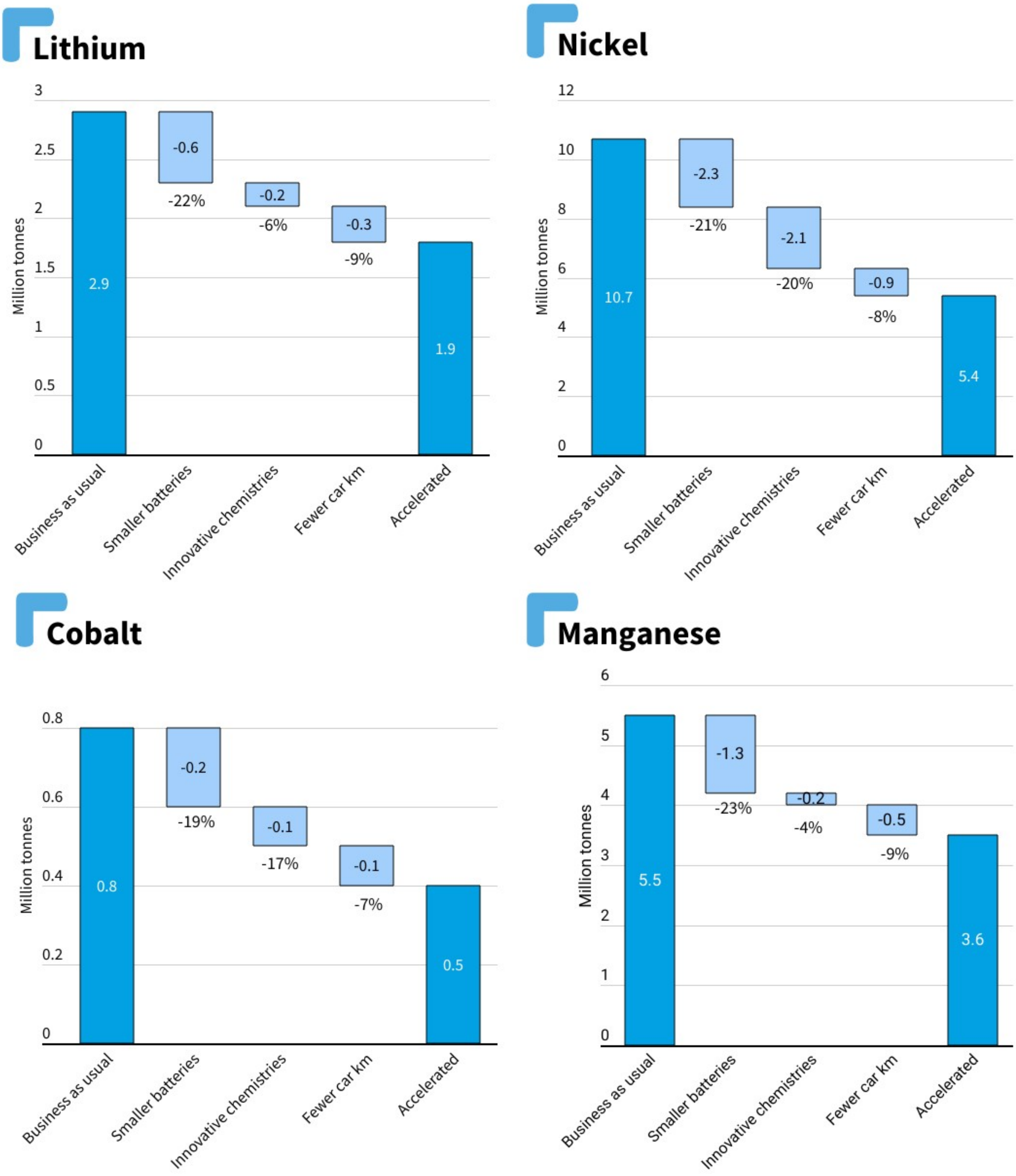
Manganese is emerging as a partial substitute for cobalt and even nickel in certain chemistries as it is more abundant and has a lower cost, while providing energy densities similar to nickel-rich chemistries [14]. The demand for it can be lowered too with technological and car usage changes by 35% in the Accelerated scenario and by 45% in the Aggressive scenario, respectively (Fig. 6).

3.2 What are the contributing factors driving less raw materials needed?

The analysis shows that battery size, chemistry and car usage factors play important roles in reducing the demand for raw materials in electrified passenger transport, although smaller batteries have the potential to exert a more substantial influence on reducing raw material demand. Battery technological advancements in electric vehicles such as battery size optimisation and commercialisation of innovative chemistries can decrease the need for additional raw materials and reduce the social and environmental impacts associated with mineral extraction and processing. Furthermore, embracing sustainable commuting practices such as fewer car distance travelled, higher usage of public and active modes of transport and increased car occupancy can lower the demand for private vehicles and promote resource efficiency.

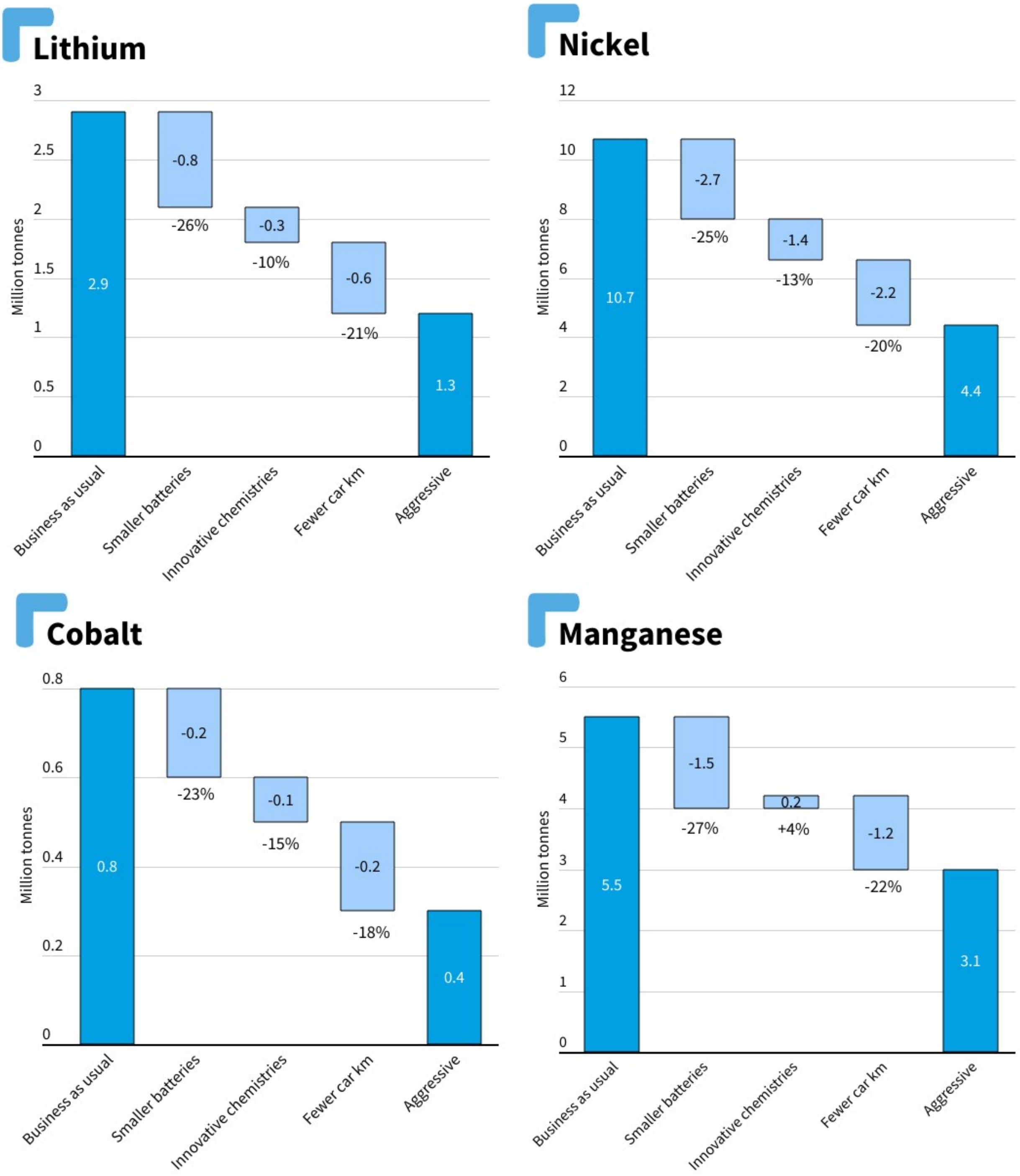
As shown in the Results section (Fig. 2), cumulative demand could be reduced substantially in the Accelerated and Aggressive scenarios. In the Accelerated scenario, using smaller car batteries would lead to a decline of 22% for lithium, 21% for nickel, 19% for cobalt and 23% for manganese. Adopting emerging chemistries would result in 6% less lithium, 20% less nickel, 17% less cobalt and 4% less manganese. At the same time, decreasing the car km driven can cut the demand by 9% for lithium and manganese, 8% for nickel and 7% for cobalt (Fig. 7).

When looking at the contribution of the factors in the Aggressive scenario, smaller batteries would contribute to a reduction of 23%-27%, while innovative chemistries would bring another 10%-15% reduction in lithium, nickel and cobalt demand and a 5% increase in manganese due to more widespread adoption of chemistries containing the latter. Due to the assumption that manganese-containing chemistries would be widely used in this scenario (e.g. LMFP, LMNO, LMR-NMC, NMCA and sodium-ion of layered oxide type in addition to the traditional NMC) along with some sodium-ion batteries that contain the element - manganese being an abundant mineral and a partial substitute to cobalt and/or nickel - the battery chemistry factor would actually contribute to a slight increase in the consumption. Nonetheless, this increase would be offset by the other factors, thus resulting in an overall decline in manganese consumption. Finally, changes in car usage can cut the demand by 18%-22% (Fig. 8).



Notes: Percentages are shown relative to the Business as usual scenario. Due to rounding, the numbers may not add up to the exact total shown.
Source: T&E analysis

Figure 7: Contributing factors driving reduction in raw materials in the Accelerated scenario



Notes: Percentages are shown relative to the Business as usual scenario. Due to rounding, the numbers may not add up to the exact total shown.

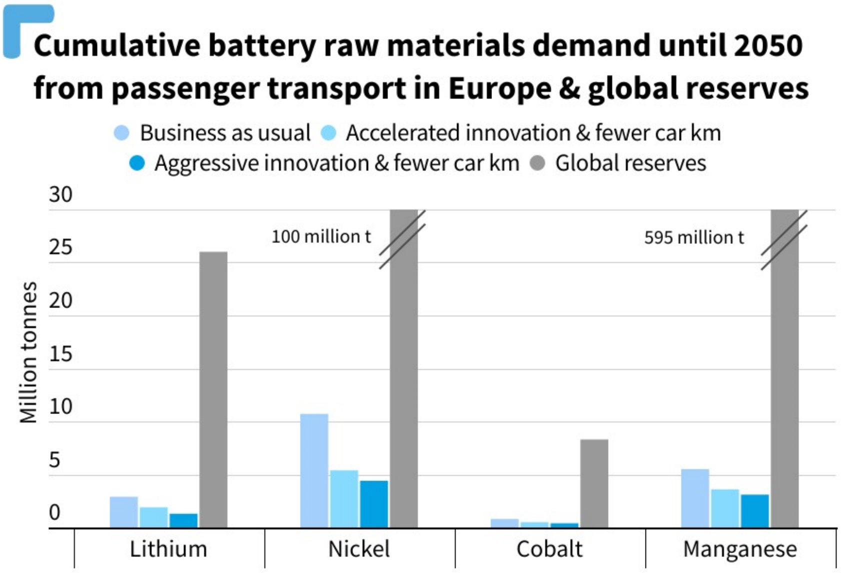
Source: T&E analysis

Figure 8: Contributing factors driving reduction in raw materials in the Aggressive scenario

3.3 What are the global reserves for battery raw materials?

According to data from the US Geological Survey [15], the earth's crust contains abundant mineral reserves for battery raw materials, suggesting a sufficient theoretical supply to meet the industry's needs (Fig. 9). Europe’s cumulative demand for lithium, nickel and cobalt between 2022 and 2050 for passenger transport would account for up to 11% of the known global reserves in the BaU scenario and the manganese demand for around 1% of the known reserves (Table 3). To put into perspective, this percentage share is lower than Europe’s share in the global passenger car fleet, which was 13% in 2022 [3].

The constraints of the industry do not necessarily lie in the mineral reserves and resources availability, but are rather related to their geographical concentration, the large investments and long lead times needed to expand the supply, along with the potential environmental and social impacts.



Note: Manganese reserves calculated assuming 35% average manganese content of the gross weight.
Source: T&E analysis, US Geological Survey (data on reserves)

Figure 9: Cumulative battery raw materials demand until 2050 from passenger transport in Europe compared to estimated global reserves

Mineral demand to reserves ratio	Business as usual scenario	Accelerated scenario	Aggressive scenario
Lithium	11%	7%	5%
Nickel	11%	5%	4%
Cobalt	10%	6%	4%
Manganese	0.9%	0.7%	0.5%

Table 3: Cumulative battery raw materials demand until 2050 from passenger transport in Europe as percentage of the estimated global reserves

4. Discussion

4.1 Raw materials demand

The analysis reveals that the electrification of the passenger transport in Europe will require large amounts of raw materials relative to today's consumption in all scenarios, even in the most radical demand reduction ones: some 1 to 3 Mt of lithium, 4 to 11 Mt of nickel, 0.4 to 0.8 Mt of cobalt and 3 to 6 Mt of manganese. This compares to 0.1 Mt of lithium, 3.1 Mt of nickel, 0.2 Mt of cobalt, 20 Mt of manganese produced globally in 2022, of all qualities and forms and for all sectors [16]. At the same time, the cumulative demand of these raw materials until mid-century, up to 20 Mt combined, represents only a fraction, tonnage-wise, of the oil consumption by cars, buses and coaches in 2022 in Europe, around 170 million tonnes of oil equivalent (Mtoe).

Additional mining will be necessary to meet Europe's growing demand for raw materials in all scenarios in the long term. But bringing new supply on stream will take time and will require capital investments. The average lead times from discovery to production can be 4 to 7 years for lithium and 15 to 20 years for nickel [17]. Therefore, investments have to be scaled up sooner rather than later in order to manage potential supply chain bottlenecks and price volatility that can slow down the energy transition.

Relative to the known global reserves, as estimated by the US Geological Survey [18], the cumulative demand would account for 5-11% for lithium, 4-11% for nickel, 4-10% for cobalt and 0.5-0.9% for manganese. Thus, it is clear there will be no shortage of resources worldwide to electrify passenger transport in line with climate needs. This myth needs to be put to rest. Moreover, with the growing interest and demand, known reserve estimates tend to increase as well (Table 4). Because scaling the supply at the speed the electrification requires is a challenge, we must not forget about the potential to source the necessary supply from secondary sources and recycling. Especially in Europe, which has a large consumer market and some scrap volumes from scaling battery gigafactories, a large potential for secondary battery metals exists; even in 2030 up to 15% of the battery demand can be met through recycling.

Mineral reserves (in Mt)	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Lithium	3	4	13	14	21	22	26
Nickel	49	62	76	79	94	95	100
Cobalt	5	7	7	7	7	8	8
Manganese*	231	151	221	217	455	525	595

Table 4: Global reserves reported by the US Geological Survey between 2019 and 2022

*Manganese reserves calculated assuming 35% average manganese content of the gross weight.

Another challenge is to scale the supply in an environmentally sound and socially responsible manner so it does not repeat the mistakes of fossil extraction. Mining, like any processes, cannot be impact free. However, using the best available technologies and best practices can reduce the impact significantly to make operations respect their local environments and communities. Many raw materials - just like oil and gas - are often sourced from regions with low governance scores and/or high emissions intensity [19], so technology transfer, cooperation and strong global standards (e.g. IRMA - The Initiative for Responsible Mining Assurance) are key.

Nickel is a good example, as the metal will experience one of the highest demands in terms of tonnages, according to T&E analysis. However, depending on how and under what conditions it is produced, nickel can raise sustainability and governance concerns, necessitating stronger frameworks and policies. For example, extracting and processing nickel in Indonesia, the world's largest nickel mining country, can lead to deforestation if not done properly, is carbon intensive and could pose issues with tailings disposal (although problematic deep sea tailings disposal has been put on hold) [20, 21]. Measures to improve nickel's credentials include the usage of renewable energy and the implementation of responsible mining techniques such as those under the IRMA standard to minimise environmental and social impacts. Downstream players, notably electric vehicle manufacturers, have a big role to play to drive the improvement of the conditions on the ground via strong due diligence requirements, which are key.

As another example, cobalt mining has been linked to safety risks and child labour in the DRC. Nonetheless, efforts are being made to promote transparency, traceability and ethical practices in the cobalt supply chain. Ongoing engagement among multiple stakeholders, including governments, companies and civil society, remains important to drive improvements in the situation and implement responsible mining methods that prioritise worker safety, fair labour practices and environmental protection.

It is thus crucially important that future supply expansion is accompanied by strict environmental and social standards and have communities on board via robust engagement practices.

As stressed above, recycling will play an essential role in developing a circular economy, reducing the demand for virgin materials. Unlike traditional cars running on fossil fuels in a linear “take-make-dispose” model, where resources are extracted, used and then discarded, electric vehicle batteries can be recycled allowing valuable materials to be recovered and reused in new batteries in a closed-loop system. In the short term, with the scaling up of battery factories in Europe, the main source of feedstock will be the manufacturing scrap. As the electrical vehicle fleet matures over time, a greater supply of end-of-life batteries will become available for recycling from 2030 onwards.

4.2 Factors driving the reduction of raw materials

The analysis shows that technological and car usage factors both play an important role in reducing the reliance on critical raw materials of the passenger transport sector. In both Accelerated and Aggressive scenarios the largest reduction is driven by going to smaller batteries.

Battery size

Smaller battery sizes contribute to a decline in raw materials demand of 19%-23% in the Accelerated scenario, and 23%-27% in the Aggressive one.

The two proposed scenarios assume a widespread adoption of cars with battery capacities sufficient for the daily commute, e.g. averaging around 40-50 kWh by 2050 compared to 73 kWh in BaU. Already today, cars equipped with 25-30 kWh sodium-ion batteries, which can reach 250-300 km in one charge (CLTC), are being tested in China. Such cars would be well-suited for daily short-distance travel especially in urban areas and represent a less expensive option for cost conscious consumers.

Shifting to smaller batteries can be achieved through two approaches: either by adopting batteries with shorter ranges while maintaining the car size constant, or by downsizing the vehicles themselves. When considering other materials such as steel and aluminium, downsizing vehicles emerges as the best strategy to save valuable resources. This approach not only optimises resource utilisation but offers social benefits in terms of affordability for consumers. Moreover, from an industrial perspective, it enables the production of large volumes globally. By expanding their small entry level cars offer, European carmakers can stay competitive in the global market, especially in regions with high population densities and urbanisation rates where such vehicles are sought after for their affordability and practicality.

Concerningly, in 2022 sports utility vehicles (SUVs) accounted for 52% of passenger car sales in the EU27 [22]. SUV models are more expensive and generate higher profit margins for carmakers who are, thus, incentivised to produce them over compact models. However, they - especially the larger models such as pick-up trucks that now enter the EU market following the US success - require larger batteries that contain more critical raw materials, raising both environmental and affordability concerns. T&E ran a sensitivity scenario in which all passenger cars are SUVs with battery capacity of 100 kWh. All things being equal, this would require on average 37% more raw materials, i.e. an additional 1.1 Mt of lithium, 4.0 Mt of nickel, 0.3 Mt of cobalt and 2.0 Mt of manganese compared to the BaU.

Therefore, ensuring battery and vehicle downsizing becomes imperative for achieving a just transition that addresses environmental concerns, ensures affordable electrification and keeps Europe’s auto industry competitive globally.

Battery chemistry

Battery chemistry, in contrast, brings a 4%-20% reduction across the Accelerated and the Aggressive scenarios for all metals, except manganese in the Aggressive scenario. Manganese is likely to emerge as a (partial) substitute to cobalt and/or nickel due to its abundance and thus its consumption is expected to continue to increase from the relatively low levels today.

Moving away from battery chemistries that are intensive in critical raw materials and engineering out certain metals from batteries, such as cobalt, nickel and/or lithium, has the potential to alleviate the demand for these materials. At the same time, such technological shifts would make electric cars more affordable, making them more accessible to wider parts of the population.

In the Accelerated and Aggressive scenarios, nickel-rich chemistries (NMC, NCA) will lose market share to lower cost iron-based chemistries (LFP, LMFP) and sodium-ion batteries, which have already seen important technological advancements recently, while manganese-rich chemistries (LMNO, LMR-NMC) will maintain some share especially in the bus and coach segments .

LFP batteries have been popularised in China due to their safety, longer cycle life and lower cost than NMC, where they accounted for over 60% of batteries installed in vehicles last year. Until recently, companies outside China underestimated their potential, but they are starting to gain attention in Europe (notably Norway) [23]. Shifting towards LFP batteries will help reduce dependence on scarce resources and enhance the diversification of battery chemistries. Further, LMFP batteries (LFP with manganese addition), just now being commercialised in China, are expected to achieve superior performance compared to LFP in terms of energy density and at lower costs compared to NMC [24]. Manganese-rich LMNO, whose development is underway, can represent a high performance, cobalt-free alternative to NMC and NCA.

But perhaps the most groundbreaking technology that has garnered widespread attention recently represents the sodium-ion batteries. Battery makers and car manufacturers in China have announced the commercialisation of sodium-ion batteries in cars, paving the way for a potential transformation in the automotive industry. These batteries can reduce the demand for critical raw materials due to the fact that they are manufactured using widely available and inexpensive sodium resources. While some formulations may contain nickel and manganese (the layered oxide types), others contain iron (PBAs) and all are free of lithium, making sodium-ion batteries a solution for mitigating lithium supply constraints and price fluctuations.

From a manufacturing perspective, sodium-ion batteries can be produced on the same lines as lithium-ion batteries (so-called “drop-in technology”), giving flexibility to and lowering the capital expenditure of companies already producing the latter [25, 26]. Considering these advantages and recent developments in China, it is feasible to envision a future where sodium-ion batteries become widely adopted globally and in Europe too. Overall, sodium-ion batteries could provide a low-cost solution to lithium-ion batteries that reduces the industry’s dependence on lithium resources as well as other critical raw materials and represent an opportunity for the industry to right-size the batteries of electric vehicles.

Today European battery makers do not yet manufacture this chemistry and many of the recent advancements were announced in China. Therefore, it is crucial for the region to assert its presence in the rapidly evolving battery industry by establishing independent supply chains and achieving self-reliance in battery production. To accomplish this, Europe must prioritise supporting research & development activities and scaling up industrial production of emerging technologies that are less intensive in critical raw materials.

This report focuses on selected metals used in the cathodes of batteries, rather than electrolytes and anodes materials, therefore the potential raw material demand from the latter has not been analysed here. Nonetheless, Bloomberg NEF estimates that solid-state batteries would require 45% to 130% more lithium at cell level (for the electrolyte and separator) than traditional batteries [27].

INFO BOX: Solid-state batteries

Solid-state batteries (SSB) are seen as the next generation battery technology for electric vehicles, having sparked interest from automakers in the last several years. Solid-state batteries can potentially offer enhanced safety (they are less flammable due to the solid electrolyte), longer driving ranges (due to higher energy density) and faster charging times [28]. These batteries are still under development and there are uncertainties related to the high production costs and scalability. Nonetheless, considering their advantages, they could be well suited especially for commercial vehicles and aviation applications. SSBs have cathodes similar to traditional lithium-ion batteries (NMC, NCA, LFP) and are expected to require additional lithium for the solid electrolytes and anodes.

Fewer car km and greater resource efficiency

Ensuring private cars are driven less, either by reducing the car park, reducing the amount of km those cars drive or via car-sharing/car-pooling, results in 7%-9% and 18%-22% reductions in the Accelerated scenario and Aggressive scenario respectively, compared to BaU.

Crucially, to ensure people leave their cars, their usage has to be made difficult, and unattractive - on top of promoting alternatives -, i.e. using supply-side measures to reduce the distance travelled by private vehicles. Moreover, these conditions would only work if the accessibility to services, healthcare and well-being activities in the vicinity are granted for people living both in urban and rural areas. In this report T&E talks about “fewer car km travelled”, which can be achieved by:

- A different city design and territorial planning, with less space for roads and parking, so it is less attractive to use those private cars compared to other alternatives, and with better and equitable accessibility for all segments of the population. These types of policies would lead to fewer car km travelled.
- Promotion and policy support for car-sharing, car-pooling or ride-sharing. A price on using a privately owned vehicle is one option to make this an attractive alternative. This would result in a greater utilisation of the batteries in cars, improving resource efficiency.

Of course additional policies to create an integrated mobility with reliable and affordable public and active transport alternatives is also necessary. So a mixed carrot and stick approach is needed. Dedicated policy recommendations are addressed in Section 5.

5. Policy recommendations

It remains a core priority for Europe’s Green Deal and its climate agenda to **electrify road vehicles**, including cars, vans, trucks, buses and coaches. To do so, the key policies include:

- Quickly ramping up new electric car and van sales, focusing on smaller affordable segments A-C, by achieving the EU car and van CO2 targets for 2025, 2030 and 100% zero emissions by 2035. T&E believes, certainly in Northern and Western Europe where more new cars are sold, close to 100% cars and vans can be electric already by 2030.
- Ambition pre-2035 should be accelerated, notably in corporate and urban fleets that drive twice more km than private cars and where the business case to go electric already exists. This should be done via strong corporate tax measures, as well as national and EU fleet mandates for all corporate registrations to be zero emission no later than 2030.
- Similarly for most trucks, the EU truck CO2 standards are needed to ramp up the electric sales by 2030 and go to fully zero emission sales by 2035. Urban buses should be all electric no later than 2030.

But alongside an ambitious electrification agenda policy measures at EU, national and local levels are needed to **shift the technology** towards rightly sized and smaller vehicles (especially in the case of private cars), as well as to stimulate the technological innovation for battery chemistries with less critical metals.

At **European level**, these policies include:

- Either as a separate EU regulation or as part of the 2026 Cars CO2 review, add a component on the resource efficiency of zero emission vehicles, to stimulate the sales of efficient and smaller

electric cars (while penalising the SUV models). Similarly, ambitious policy and financial support to roll out sufficient public charging networks is key to downsizing electric vehicles.
- Provide industrial support for the production of compact cars. E.g. funds from the new European Social Climate Fund can be used by governments to help make manufacturing of small affordable cars in Europe commercially attractive, provided they are destined for European drivers (not export).
- Accelerated R&D and industrial production support - via Horizon, Batteries Europe and the new EU Sovereignty Fund - to develop and scale up production of new battery chemistries such as LMFP, LNMO, sodium-ion batteries and other post-lithium batteries which are in very early stages of development (e.g. lithium-air batteries, lithium-sulphur, etc. - not covered in this report).
- Reward critical raw material (CRM) substitution and scaling of less CRM heavy battery chemistries a core pillar of Europe's Green Deal Industrial Plan, including the Net Zero Industry Act and the Critical Raw Materials Act.
- Prioritise integrated recycling - from pre-treatment to material recovery in a vertically integrated chain - to reduce the primary CRM demand. This should be consistently done in all EU funding support for recycling and policies, notably via strategic projects under the Critical Raw Materials Act.

Crucially, at **national level**:
- Add a weight or energy consumption component to the CO2 emissions based vehicle taxes (or to EV subsidies) across member states. This would ensure that even if electric, large SUV (and pick-up) models are taxed more than smaller A-C segment vehicles.
- Systemically add a requirement to manufacture small efficient electric cars in segments A-C as part of national industrial policy and many automotive transformation subsidy programmes, e.g. to retool factories into electric vehicles. E.g. schemes such as social leasing in France should - alongside the subsidy for drivers - include a requirement for at least a quarter of newly manufactured electric cars to be in segments A-C and under EUR 30,000.

At the local level, cities should include the weight component into parking rates, and policies on low emission zones and urban access restrictions.

Alongside reducing demand for critical raw materials via technological innovation, a set of ambitious measures to **reduce km done by private vehicles** is needed. T&E, and T&E-founded Clean Cities Campaign, recommend the following measures:
- Most cars on the road (used and sold) today are fossil cars on petrol or diesel. Shifting the consumers away from those short-term is the quickest way to avoid a 1-for-1 swap with electric cars. To reduce the numbers of and the km driven by petrol and diesel cars, Member States should implement distance-based charges, as well as external-cost charges for CO2 emissions for passenger cars on all roads.

- Cities should implement effective congestion charging and parking pricing to dissuade from using a private car.
- Cities should continue introducing and strengthening/expanding the Low- and Zero-Emission Zones. Access restriction zones have proven to be an effective tool to improve air quality, promote sustainable mobility and reduce traffic. Other Member States could follow the French example and introduce an obligation for cities [of a certain size] to implement and enforce LEZs and ZEZs.
- Limit speed on highways and residential areas is needed. This will not only reduce in-use fuel consumption, but will also make public transport alternatives attractive vs private car ownership. Member States should introduce speed limits of 100km/h on motorways, 80km/h on main roads and 30km/h in residential areas, and ensure proper enforcement. This will also improve safety.
- Implement car-sharing and car-pooling measures, such as providing dedicated high occupancy vehicle lanes and car-sharing parking spaces to reduce congestion and encourage more efficient use of transportation infrastructure, and ultimately to reduce car ownership.
- Develop integrated mobility (or mobility as a service) platforms that combine various transportation modes, including public transit, car-sharing, bike-sharing, into a single, comprehensive, on-demand mobility service.

Key to reducing demand for private cars lies in smart city and road planning policies. Member states and cities (with the financial support from the EU) should:

- Reform urban planning. Cities should focus on accessibility instead of multiplying mobility needs. This means taking away space for cars to give it back to the people and developing appropriate infrastructure for active mobility, such as cycling and walking.
- Enhance public transport infrastructure. The availability, affordability, reliability and comfort of alternatives are key elements in the choice of foregoing a private car. Cities and regions should improve the public transport network to make it match the mobility needs of the community, and introduce fair public transport fees for low-income households.
- Stop building new roads. Research shows that building extra road capacity increases traffic, hence emissions. Moreover transport ministries plan future infrastructure investments based on growth projections of traffic demand which are often unrealistic. Contrary to what Germany has been doing recently, Member States should adopt a moratorium on new road expansion. The Commission should include this in their climate & energy, as well as national budget guidelines for member states.

In conclusion, the electrification of passenger transport is essential but will require large quantities of raw materials, either via primary extraction or recycling, even with an ambitious demand reduction policy mix. According to our analysis, between 2022 and 2050 Europe will require 1 to 3 Mt of lithium, 4 to 11 Mt of nickel, 0.4 to 0.8 Mt of cobalt and 3 to 6 Mt of manganese, depending on the scenario. To smoothen the demand curve and help mitigate some of the impacts of increased extraction, it is crucial to devise well-crafted policies that promote smaller entry-level models (with smaller batteries), innovative battery chemistries that use less critical metals, measure to reduce private car travel as well as ambitious scale up of recycling. By doing so, we can effectively reduce material consumption and pave the way towards a fully sustainable and low impact passenger transport system.

6. Annex

6.1. Methodology and assumptions

In this report T&E developed three scenarios based on several factors in order to compare how the consumption of the selected battery raw materials varies across these. The factors are: battery capacity or size; battery chemistry; passenger distance travelled by transport mode (private car km vs public transport).

6.1.1 Data sources

Variables related to car km travelled, such as passenger distance travelled, usage of transport modes and car occupancy in all scenarios are based on T&E's in-house EU Transport Roadmap Model (EUTRM), which models the EU's fleet of light-duty and heavy-duty vehicles and is used to assess the impact of the CO2 standards on fleet composition, energy and oil consumption, and CO2 emissions. The source for the passenger transport activity data (in passenger-km) in the Business as Usual scenario is the EU Reference Scenario 2020.

Sales of electric cars, buses and coaches (ZEV uptake) are based on the ambitious T&E scenario, which assumes a total car electrification by 2032 supported by a faster corporate fleet electrification. Buses are expected to reach full electrification by 2027 and coaches by 2035.

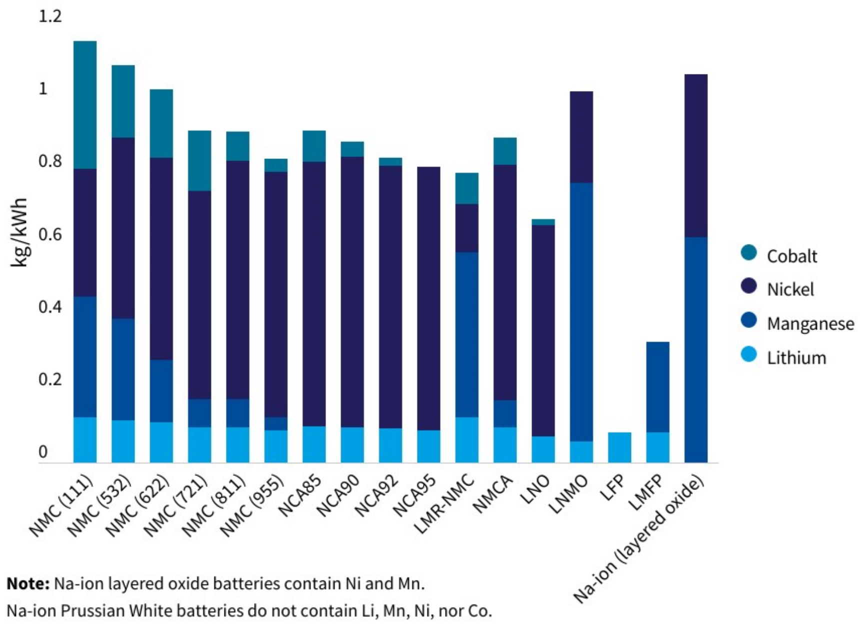
Battery capacities (or battery sizes) are based on LMC Automotive data in the case of cars and on TNO in the case of buses in BaU, and estimated by T&E for the two segments in the Accelerated and Aggressive scenarios. Coach data was sourced from TNO [3, 4].

Battery chemistry projections are based on BloombergNEF data available until 2035 and estimated thereafter in BaU and have been developed by T&E based on expert evidence available in the Accelerated and Aggressive scenarios.

The metal intensity for most chemistries was sourced from BloombergNEF, while for sodium-ion batteries it was estimated based on Wood Mackenzie data.

6.1.2 Calculation steps

The annual sales of new electric vehicles was calculated using the vehicle sales output from T&E EUTRM and zero-emissions uptake projections. Then, taking into account the average battery capacities, the demand for batteries (in GWh) was calculated. The net demand for lithium, nickel, cobalt and manganese was derived based on the chemistry mix and the metal intensity (or metal mass, measured as kg/kWh) for each chemistry. This data was retrieved from multiple sources such as BloombergNEF and Wood Mackenzie. LMFP data was estimated based on industry sources [29]. It must be noted that, due to lack of detailed data, the sodium-ion battery projections of this analysis assume a split composition, with half of the volumes being layered oxide sodium-ion (containing critical raw materials like manganese and lithium) and the other half comprising Prussian White sodium-ion without critical raw materials (which includes elements such as iron, among others).



Note: Na-ion layered oxide batteries contain Ni and Mn.
Na-ion Prussian White batteries do not contain Li, Mn, Ni, nor Co.
Source: Based on data from BloombergNEF, Wood Mackenzie

Figure 11: Metal content by chemistry

The battery production process involves certain material losses which have to be added to the net demand, resulting in a gross demand. BloombergNEF estimates various yield losses during the manufacturing stages: 5% inactive material, 15% material loss during the formation cycle and 5% overall waste material [30].

The volumes were estimated in tonnes of contained lithium, nickel, cobalt and manganese respectively.

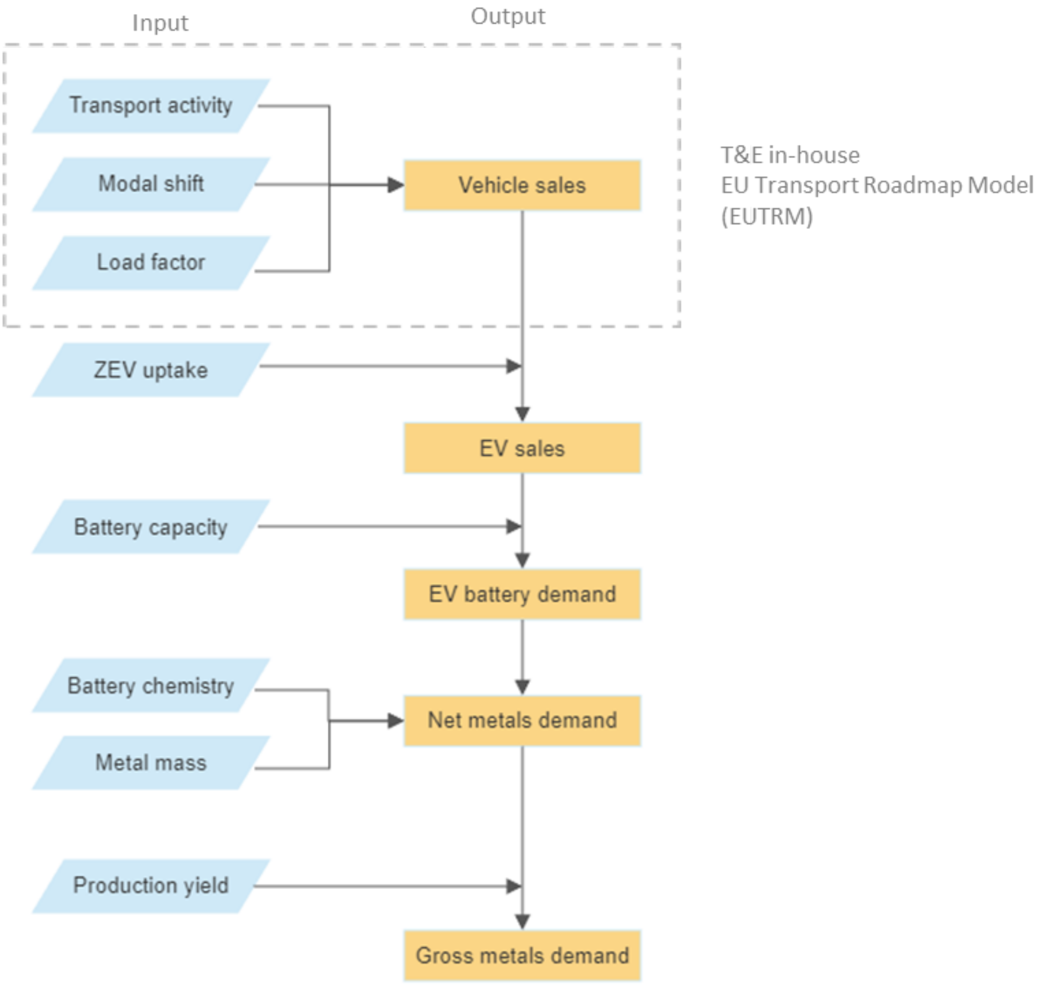


Figure 12: The main calculation steps for estimating the raw materials demand

6.1.3 Assumptions

The analysis assumes full electrification of cars, buses and coaches in line with Europe's 2050 zero emissions goal and the global Paris agreement. Also, it considers the same electrification uptake across all three scenarios, i.e. full electrification achieved by 2032 for cars, by 2027 for buses and by 2035 for coaches.

Share of electric	**2025**	**2030**	**2035 on**
Cars	24%	80%	100%
Buses (100% in 2027)	23%	100%	100%
Coaches (battery & fuel cell)	3%	64%	100%

Scenario 1: Business as usual (BaU)

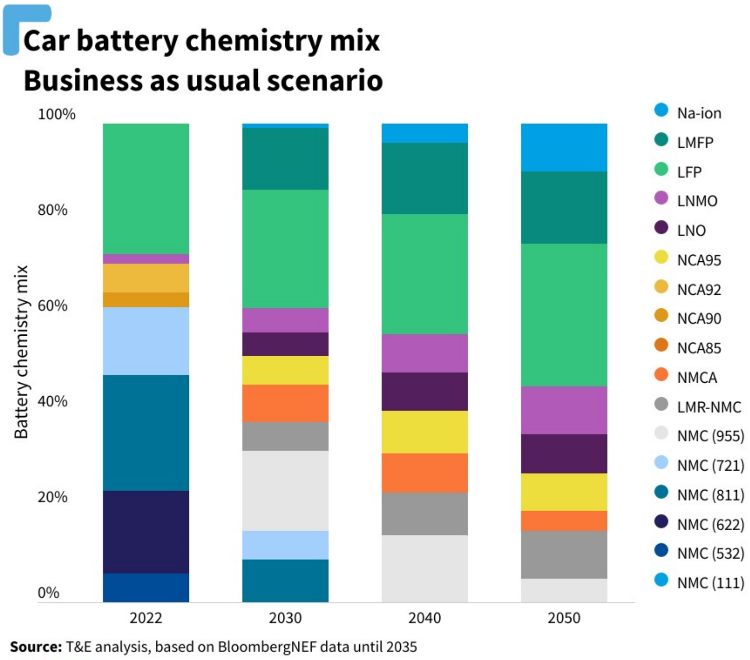
Passenger distance travelled, transport mode usage and car occupancy: Aligned with the EU Reference Scenario 2020, which projects energy, transport and greenhouse gas emissions trends to 2050 for the EU member states.

Battery size: Average car battery sizes follow the industry's trend towards larger size batteries (based on LMC Automotive data). Bus and coach battery capacities are expected to decline, while fuel cell coach batteries are assumed to stay constant throughout the period. These figures are based on TNO data for long haul trucks with a 500 km range. Considering the similarities between coaches in trucks in battery range and chemistry, it was assumed that developments made in the trucks segment can be replicated in coaches. Also, due to lack of additional data on coaches, the same battery capacities are used in all three scenarios.

Battery capacity (kWh)	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Cars	70	73	73	73	73	73
Buses	281	253	253	252	252	252
Coaches - battery electric	777	627	622	616	616	616
Coaches - fuel cell	140	140	140	140	140	140

Battery chemistry: The starting point chemistry projections is BNEF data available until 2035. By 2050, the mix for cars includes 45% cobalt- and nickel-free, iron-based chemistries (LFP, LFMP) and 45% of nickel-rich lithium-ion batteries that are predominantly used today (NMC, NCA) and manganese-rich formulations (LMR-NMC, LNMO). Considering the recent advances in sodium-ion batteries, they were projected to achieve a market penetration rate of up to 10% by 2050 and find application in the small car segment.

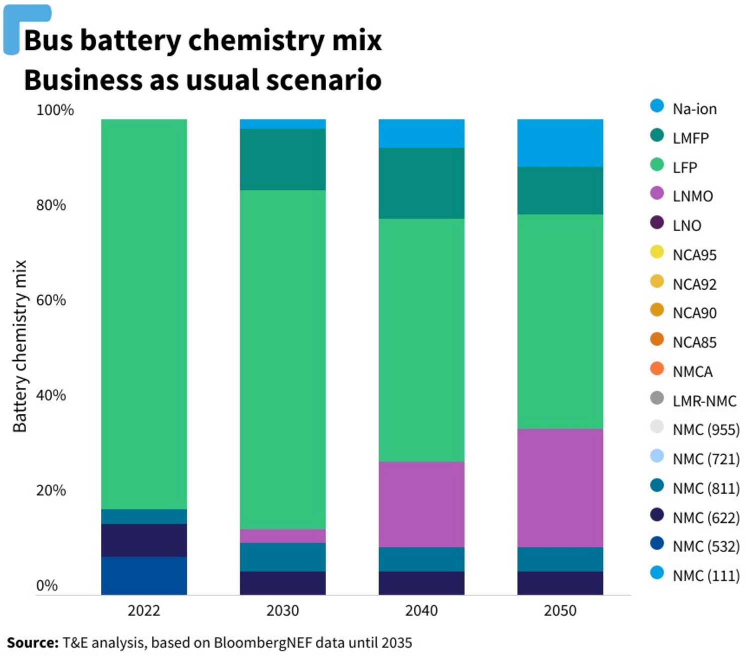
Buses would use a large share of iron-based chemistries along with manganese-rich chemistries (80% altogether) and some nickel-rich and sodium-ion. Coaches, which need more driving autonomy than buses, will be dominated by nickel-rich and manganese-rich chemistries (90% altogether). Sodium-ion batteries do not make a big contribution here in this scenario, instead more resource intensive technologies as today are used.



Car battery chemistry mix
Business as usual scenario

Source: T&E analysis, based on BloombergNEF data until 2035

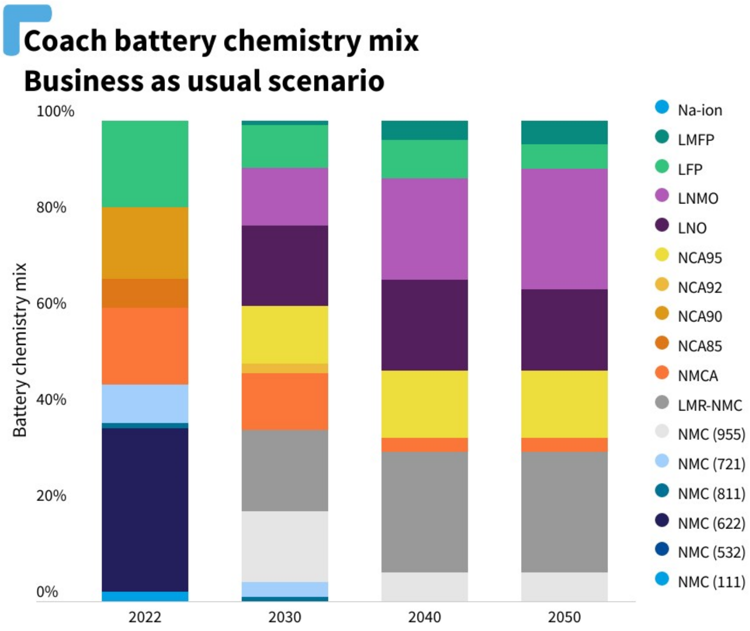
Figure 13: Battery chemistry mix for cars in the Business as Usual scenario



Bus battery chemistry mix
Business as usual scenario

Source: T&E analysis, based on BloombergNEF data until 2035

Figure 14: Battery chemistry mix for buses in the Business as Usual scenario


Coach battery chemistry mix
Business as usual scenario

Source: T&E analysis, based on BloombergNEF data until 2035

Figure 15: Battery chemistry mix for buses in the Business as Usual scenario

Scenario 2: Accelerated innovation and fewer car km scenario (or accelerated scenario)

Passenger distance travelled: Modelled to decrease by 5% in 2030 and 10% in 2040 compared to BaU.

Transport modes usage: This scenario involves some modal shift from passenger cars to public transit and active modes, with half of the shift being allocated towards buses for urban travel and coaches and the other half towards railway and active modes (not covered in this report).

Car occupancy: Modelled to be higher by 5% in 2030 and 10% in 2040 compared to BaU, i.e. 2.2 people per car on average compared to just 2.0 on average in BaU.

Fewer car km factors	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Distance travelled*	- 3%	-5%	-8%	-10%	-10%	-10%
Transport modes usage*	3%	6%	9%	12%	12%	12%
Car occupancy*	3%	5%	8%	10%	10%	10%

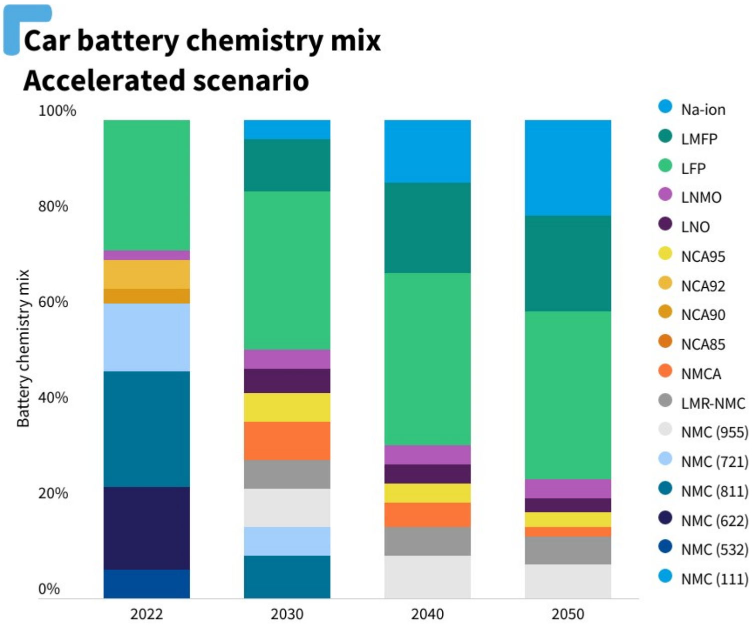
*Compared to BaU.

EV sales: The above car usage assumptions would result in lower car and van sales and higher bus and coach sales compared to BaU.

Battery size: Policies on car usage and size would shift the focus from larger batteries to more efficient and optimised battery designs and contribute to the adoption of lower battery capacities in cars, i.e. from an average 68 kWh in 2025 to 56 kWh in 2035 and 50 kWh after 2040. Capacities of electric bus batteries would increase to 290 kWh in 2035 and 300 kWh in 2040 in light of more intense usage as people shift from cars. Battery sizes of coaches are similar to those in BaU due to lack of data and uncertainty as to how the segment would develop in the future.

Battery capacity (kWh)	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Cars	68	63	56	50	50	50
Buses	281	281	290	300	300	300
Coaches - battery electric	777	627	622	616	616	616
Coaches - fuel cell	140	140	140	140	140	140

Battery chemistry: In this scenario the battery chemistries of cars are projected to comprise a higher share of nickel- or cobalt-free chemistries such as iron-based (55%) as well as sodium-ion batteries (20%), which will soon be commercialised in China. For electric buses it was assumed mostly iron-based (55%) and sodium-ion (20%), while coaches would rely on iron–based (40%) as well as nickel-based and manganese-rich chemistries (50% altogether), along with a small share of sodium-ion.



Source: T&E analysis

Figure 16: Battery chemistry mix for cars in the Accelerated scenario

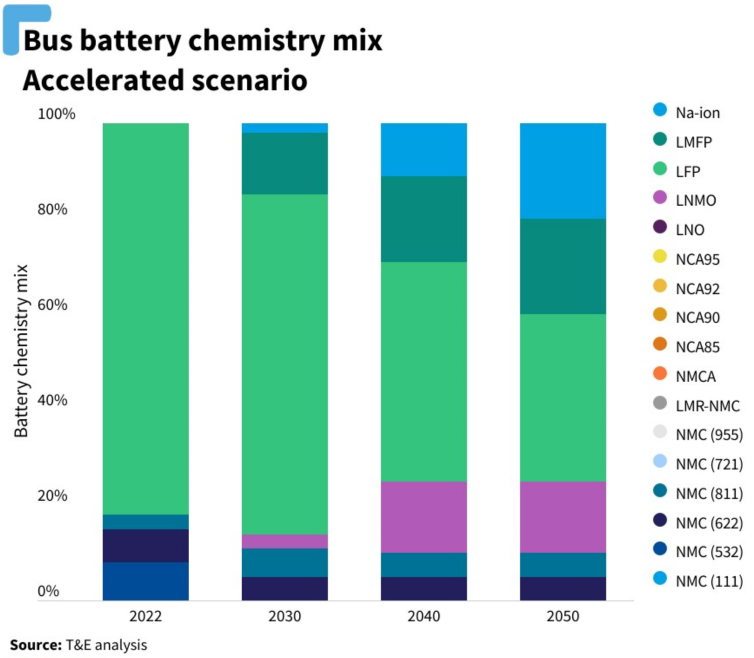


Figure 17: Battery chemistry mix for buses in the Accelerated scenario

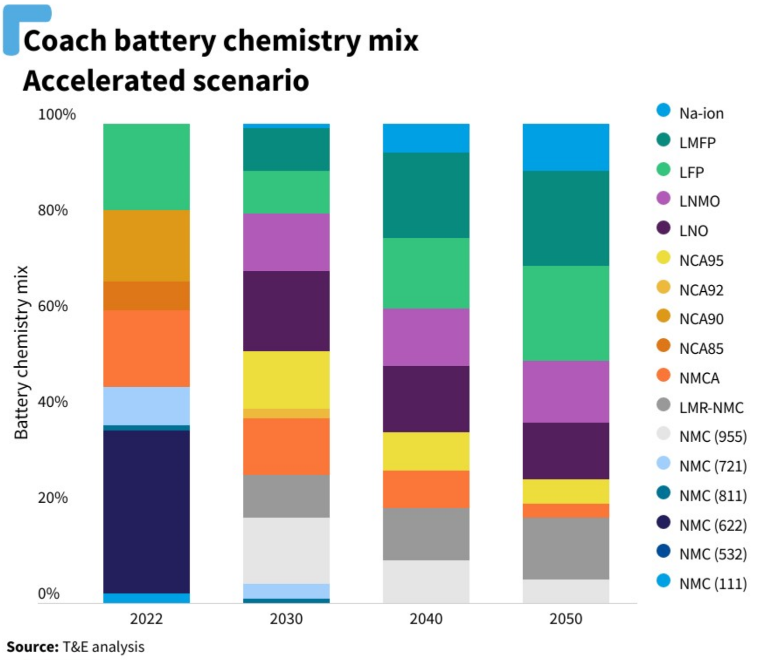


Figure 18: Battery chemistry mix for coaches in the Accelerated scenario

Scenario 3: Aggressive innovation and fewer car km scenario (or aggressive scenario)

Passenger distance travelled: Reduced by 15% in 2030 and 25% in 2040 compared to BaU.

Transport modes usage: This scenario involves a larger modal shift towards public transit and active modes, half of which directed to buses and coaches (and the other half to railway and active modes).

Car occupancy: Modelled to increase by 10% in 2030 and 25% in 2040 compared to BaU, i.e. 2.5 people per car on average compared to just 2.0 on average in BaU.

Fewer car km factors	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Distance travelled*	-8%	-15%	-20%	-25%	-25%	-25%
Transport modes usage*	8%	15%	23%	30%	30%	30%
Car occupancy*	5%	10%	18%	25%	25%	25%

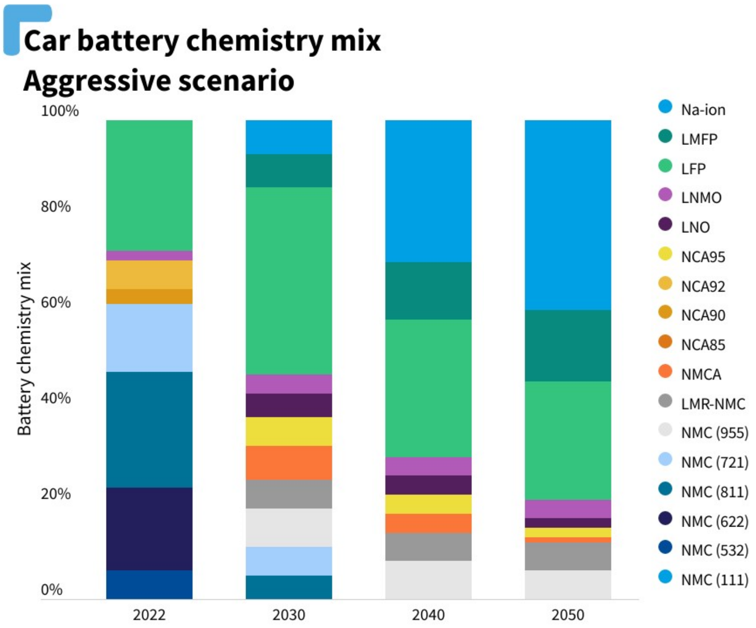
*Compared to BaU.

EV sales: The electric vehicle shares compared to total vehicle sales remain the same as in the Accelerated scenario, but the car usage assumptions above would result in overall lower electric car sales and higher electric bus and coach sales than in the previous scenarios.

Battery size: Availability of charging infrastructure, strict city planning policies and radical measures on car and van usage would shift the focus from larger batteries to small and innovative technologies even more in this scenario than in the Accelerated scenario. The car battery capacity would be reduced from 68 kWh in 2025 to 50 kWh in 2035 and 40 kWh after 2040, while that of electric buses would increase to 290 kWh in 2035 and 300 kWh in 2040 (as in the Accelerated scenario), in order to accommodate increased usage of public transportation.

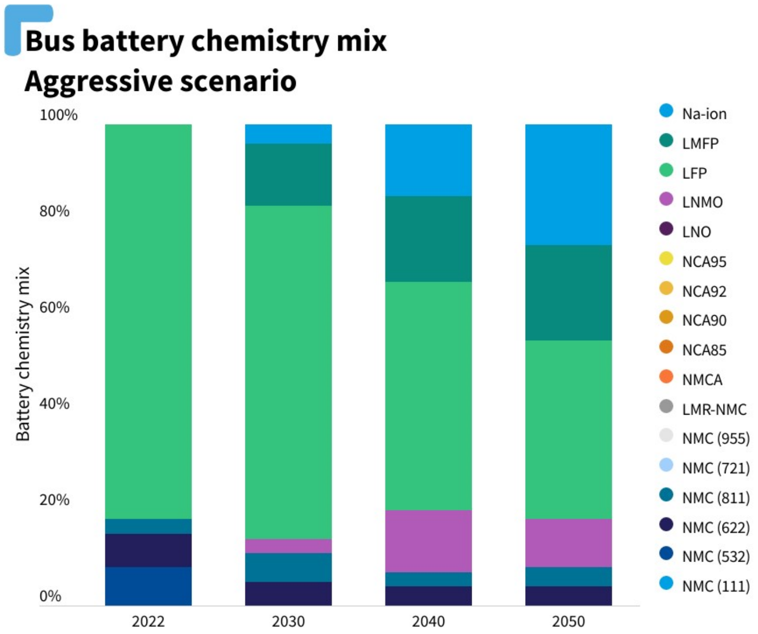
Battery capacity (kWh)	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Cars	68	60	50	40	40	40
Buses	281	281	290	300	300	300
Coaches - battery electric	777	627	622	616	616	616
Coaches - fuel cell	140	140	140	140	140	140

Battery chemistry: This scenario assumes emerging technologies such as sodium-ion being prevalent in electric cars (40%) along with iron-based chemistries (40%). Iron-based formulations would dominate the bus chemistry mix (almost 60%), along with sodium-ion (25%). Coaches will rely on iron-based (45%) as well as nickel-based and manganese-rich chemistries (40% altogether).


Car battery chemistry mix
Aggressive scenario

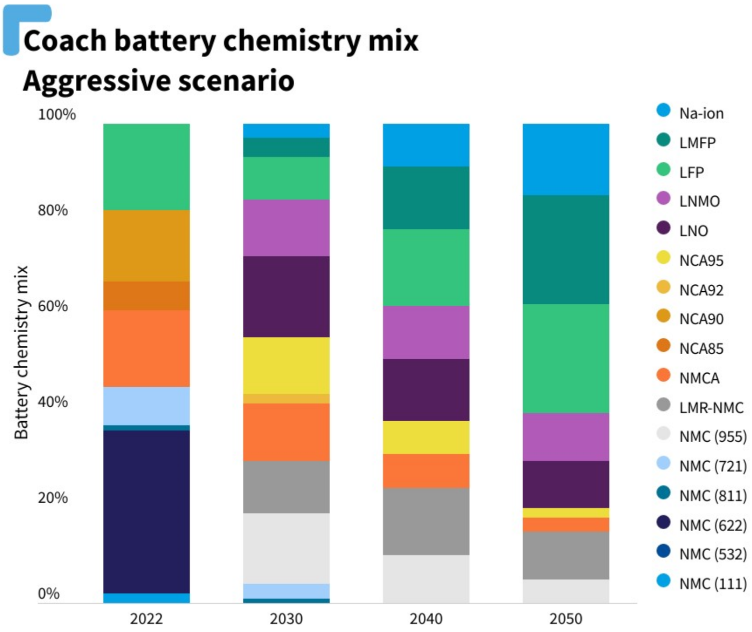
Source: T&E analysis

Figure 19: Battery chemistry mix for cars in the Aggressive scenario


Bus battery chemistry mix
Aggressive scenario

Source: T&E analysis

Figure 20: Battery chemistry mix for buses in the Aggressive scenario



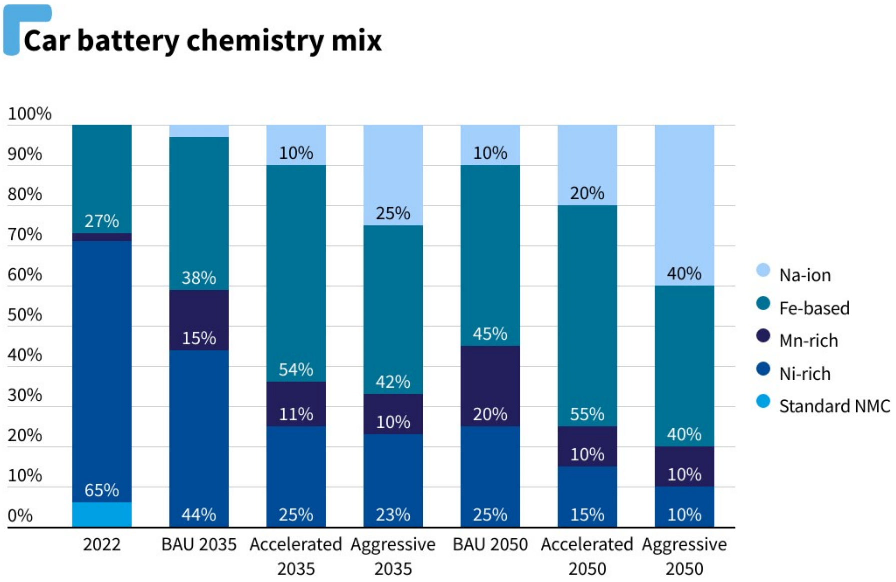
Source: T&E analysis

Figure 21: Battery chemistry mix for coaches in the Aggressive scenario

6.1.4 Chemistry mix comparisons

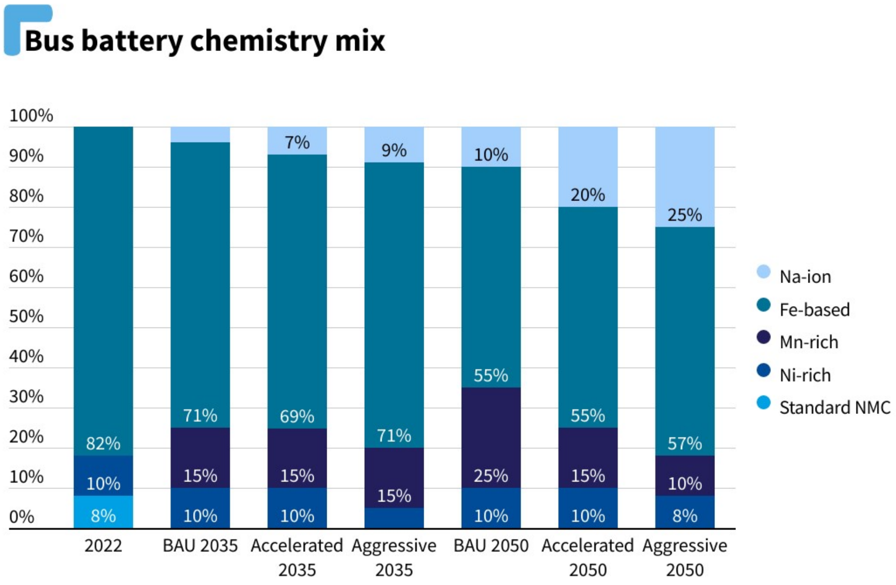
For simplicity, the chemistries were clustered into several categories:

- Standard NMC (lithium nickel manganese cobalt oxide): NMC111 up to NMC532;
- Nickel-rich: NMC622 to NMC96Ni, NCA85 to NCA95 (lithium nickel cobalt aluminium oxide), LMCA (lithium manganese cobalt aluminium oxide), LNO (lithium nickel oxide);
- Manganese-rich: LMR-NMC (lithium-manganese rich NMC), LNMO (lithium nickel manganese oxide);
- Iron-based: LFP (lithium iron phosphate), LMFP (lithium manganese iron phosphate);
- Sodium-ion batteries.


Car battery chemistry mix

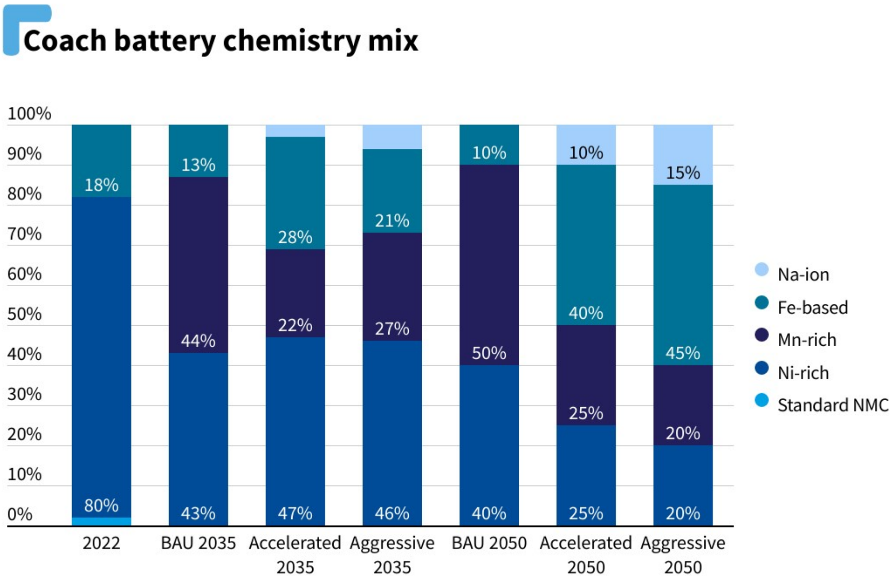
Notes: Standard NMC: NMC111 up to NMC 523. Ni-rich: NMC622 to NMC96Ni, NCA85 to NCA 95, LMCA, LNO. Mn-rich: LMR-NMC, LNMO. Fe-based: LFP, LMFP.
Source: T&E analysis, BAU based on BloombergNEF data until 2035

Figure 22: Battery chemistry mix for cars across scenarios (2035 & 2050)


Bus battery chemistry mix

Notes: Standard NMC: NMC111 up to NMC 523. Ni-rich: NMC622 to NMC96Ni, NCA85 to NCA 95, LMCA, LNO. Mn-rich: LMR-NMC, LNMO. Fe-based: LFP, LMFP.
Source: T&E analysis, BAU based on BloombergNEF data until 2035

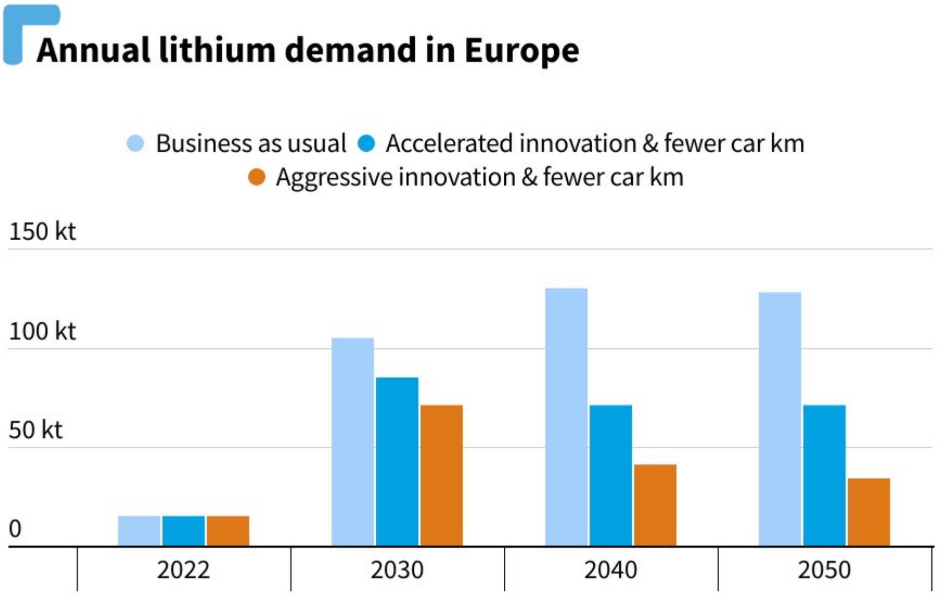
Figure 23: Battery chemistry mix for buses across scenarios (2035 & 2050)



Notes: Standard NMC: NMC111 up to NMC 523. Ni-rich: NMC622 to NMC96Ni, NCA85 to NCA 95, LMCA, LNO. Mn-rich: LMR-NMC, LNMO. Fe-based: LFP, LMFP.
Source: T&E analysis, BAU based on BloombergNEF data until 2035

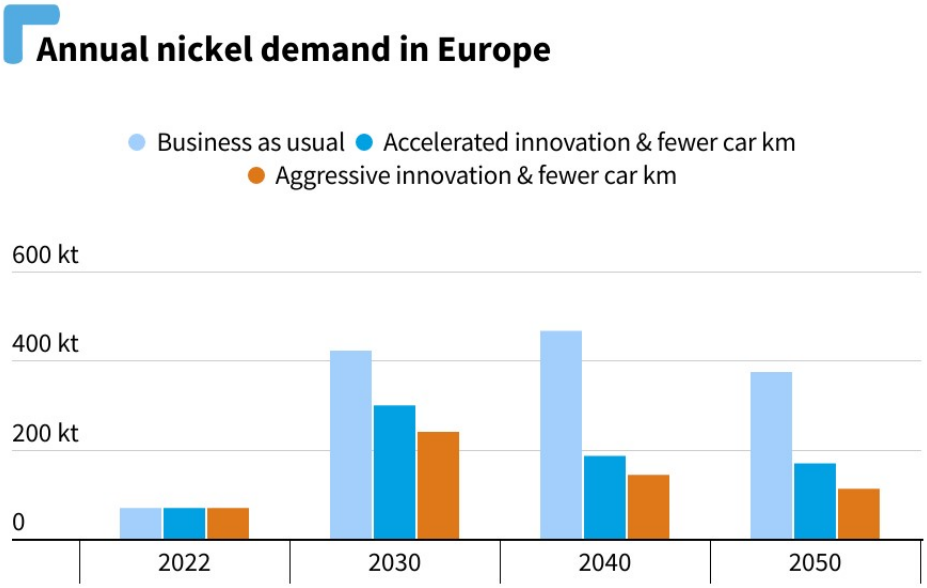
Figure 24: Battery chemistry mix for coaches across scenarios (2035 & 2050)

6.2 Annual raw materials demand



Source: T&E analysis

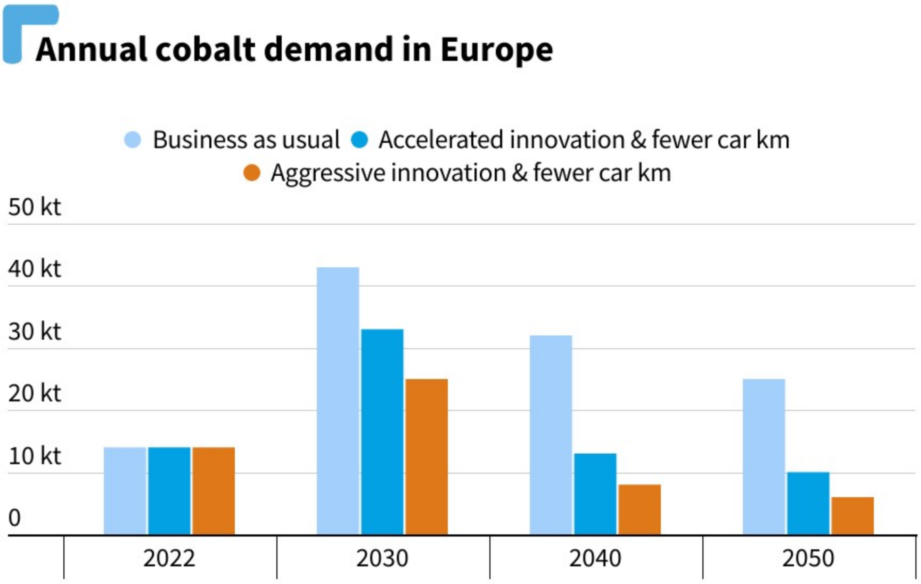
Figure 25: Annual lithium demand in Europe across scenarios



Annual nickel demand in Europe

Source: T&E analysis

Figure 26: Annual nickel demand in Europe across scenarios



Annual cobalt demand in Europe

Source: T&E analysis

Figure 27: Annual cobalt demand in Europe across scenarios

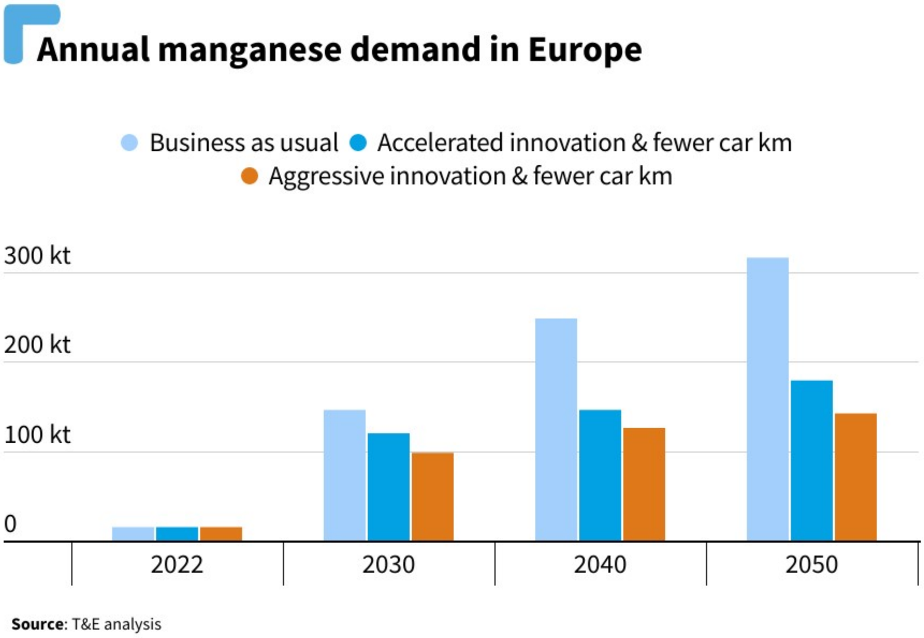


Figure 28: Annual manganese demand in Europe across scenarios

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