From dirty oil to clean batteries

Batteries vs. oil: a systemic comparison of material requirements

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Executive Summary

In light of the urgency to decarbonise the transport sector, batteries offer the best route to a carbon free road transport system and are the key technology underpinning the transition of road vehicles to zero emissions, freeing the sector from its dependency on fossil-fuels. With battery electric vehicles (BEV) expected to replace conventional cars in Europe, the demand in battery cells and battery raw materials like lithium, nickel and cobalt is set to grow in the coming years. But how can the demand for battery materials be met sustainably? And how does a battery-based road transport system compare to the current fossil driven road mobility? In this report T&E analyses forecasted supply and demand of battery cells and associated raw materials in Europe, looking at how recycling can reduce the need for battery primary materials. The report highlights the superiority of the battery-based mobility system - whether on raw material demand, energy efficiency or cost - compared to the current oil-based system.

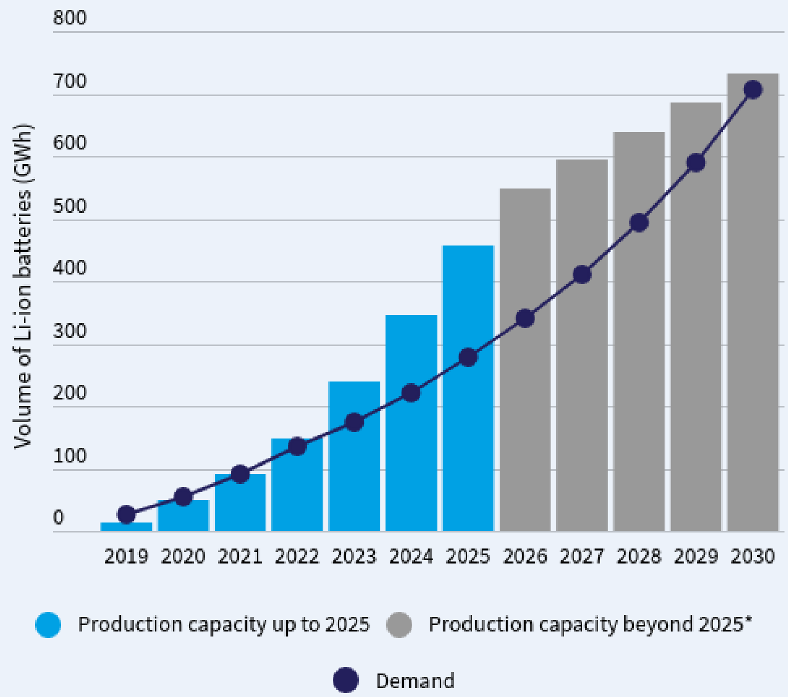
Enough "made in EU" batteries for the electric vehicle market

With electric vehicle (EV) sales surging, the total demand for batteries in Europe is expected to reach close to 300 GWh in 2025, more than 700 GWh in 2030 and more than 1,300 GWh in 2035[1]. While there was, until 2020, a shortage of batteries produced in Europe to equip all the electric vehicles placed on the market, supply could match demand as soon as 2021 at around 90 GWh if planned production comes on time.

There are 22 battery gigafactories planned to be set up in the next decade in the EU, with total production capacity going from 460 GWh in 2025 (enough for around 8 million battery electric cars) to 730 GWh in 2030, which is enough for the expected EV market. This shows that policies aimed at boosting the EV market also bring the supply chain and investments into domestic manufacturing. If the production is to ramp up on schedule, the battery supply could even surpass the European demand in the mid-2020s with both supply and demand expected to be on par at around 700 GWh in 2030.

[1] includes demand for BEVs and PHEVs cars and covers light and heavy duty vehicles as well as stationary storage

European battery production will meet demand as early as 2021



*Beyond 2025, the expected battery cell production capacity is more uncertain given most announcements are limited to a timeframe of several years.
Source: T&E monitoring of market announcements and T&E modelling of expected battery demand. Scope: EU27 + UK

More (batteries) with less (materials)
With European production increasing, so will the demand for raw materials over the next decade. However, with battery technology evolving, **less raw material will be needed to produce each kWh of an EV battery**. From 2020 to 2030, the average amount of lithium required for a kWh of EV battery drops by half (from 0.10 kg/kWh to 0.05 kg/kWh), the amount of cobalt drops by more than three quarters, with battery chemistries moving towards a lower cobalt content (from 0.13 kg/kWh

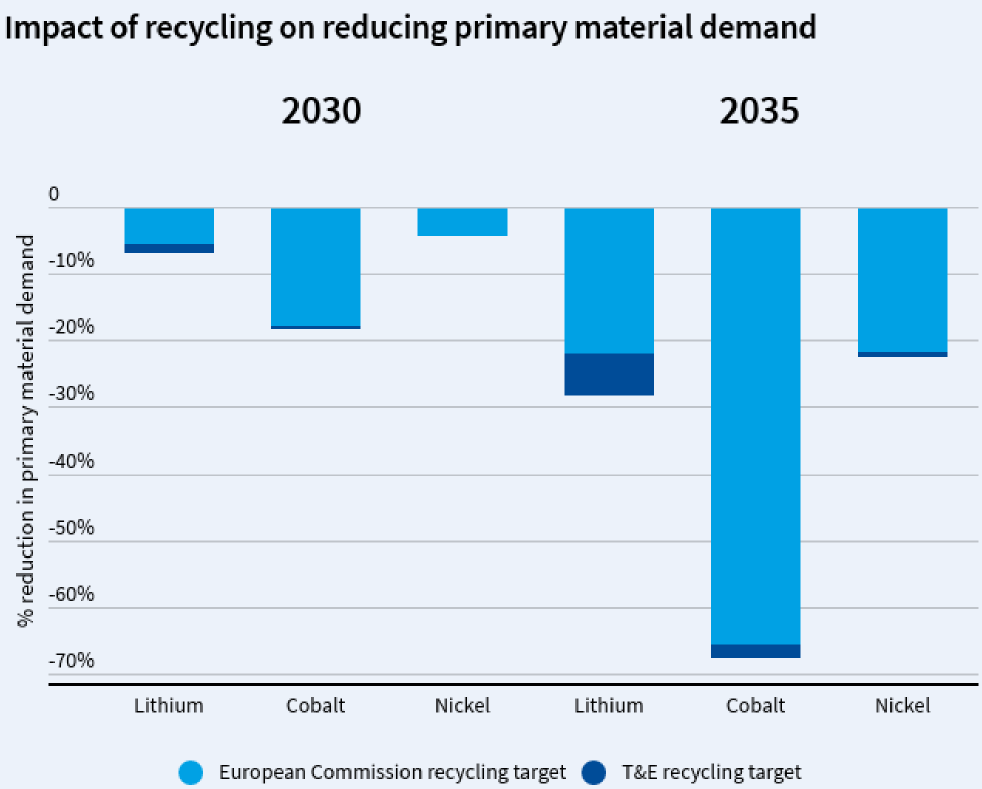
to 0.03 kg/kWh). For nickel the decrease is less pronounced - around a fifth - with new battery chemistries moving towards a higher nickel content (from 0.48 kg/kWh to 0.39 kg/kWh).

Reducing primary demand through recycling

Unlike today's fossil fuel powered cars, electric car batteries are part of a circular economy loop where battery materials can be reused and recovered to produce more batteries. Recycling of battery materials is crucial to reduce the pressure on primary demand for virgin materials and ultimately limit the impacts raw material extraction can have on the environment and on communities.

If the current recovery rates proposed in the new EU draft battery regulation are increased to current best practice, i.e. 90% for lithium (from 70%) and 98% for cobalt and nickel (from 95%), the amount of lithium in each EV battery that cannot be used again for battery production (i.e. that is lost in the recycling process) is divided by three, while the amount that can't be recovered for cobalt, nickel and copper is divided by 2.5.

When taking into account the amount of EV battery recycling, the growing raw material needs are mitigated even further. Under the Commission's proposed target, in 2030, 5% of lithium, 17% of cobalt and 4% of nickel required for EV battery production can be obtained from recycled European EV batteries. In 2035, this increases to 22% of lithium and nickel, and 65% of cobalt as more cars come to the end of life. Thanks to higher recycling targets, in 2035, the supply from recycled batteries reduces further the need for primary materials by 6% for lithium, 2% for cobalt, and 1% for nickel.

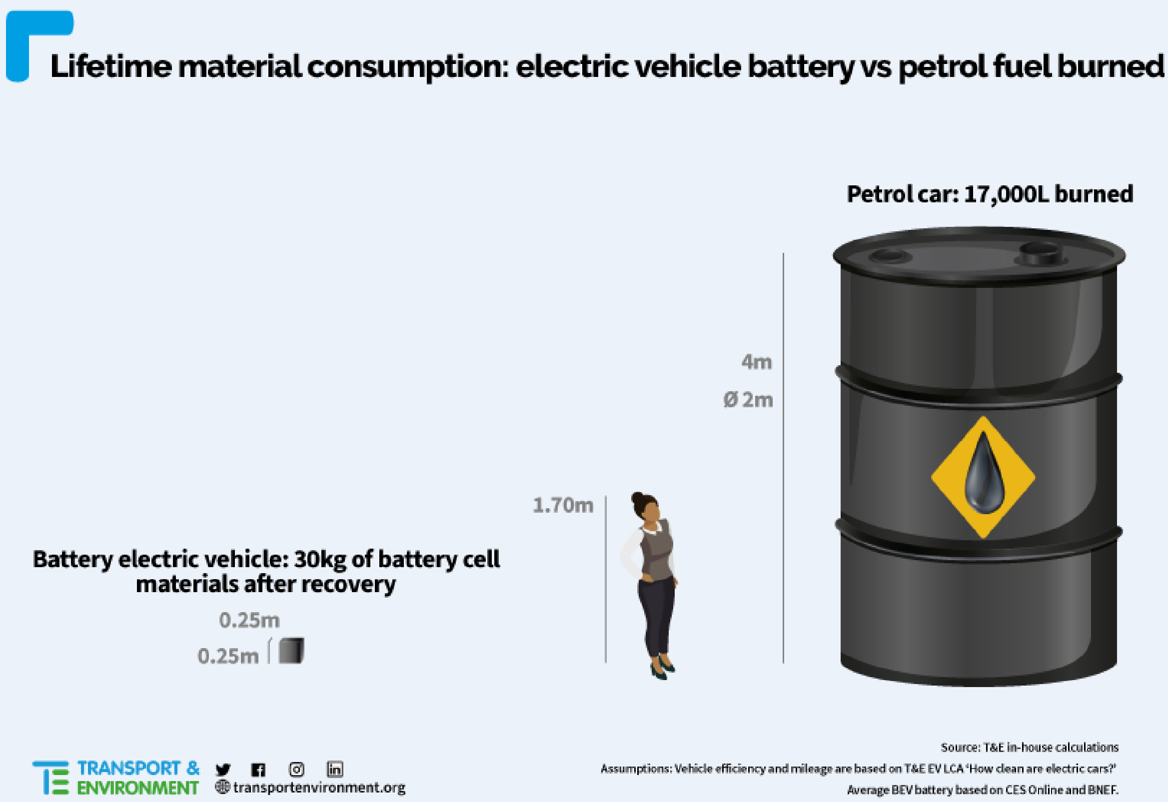


Recycling of electric vehicles starts to have a strong impact from 2030, while the recycling of portable electronics (not captured here), could already reduce the demand for primary materials in the 2020s.

Lithium, cobalt, nickel are available in sufficient quantities to enable a rapid, worldwide adoption of electric vehicles. Looking at Europe, if the current European reserves for raw materials were converted in BEV batteries, this would account for the equivalent of the lithium for 200 million BEVs produced in 2030 (or 20 million with no recycling), the nickel for 17 billion BEVs (or 300 million with no recycling) and the cobalt for 500 million BEVs (or 10 million with no recycling).

Oil vs. batteries: double standards?

While ramping up battery materials on time has its challenges, these pale in comparison to the environmental, raw material supply, and energy cost weaknesses of the current fossil-based road transport system. While internal combustion engine (ICE) cars emit toxic fumes and CO_2 causing catastrophic global warming as they drive, BEVs do not burn fuel at the tailpipe and battery materials can be reused and recovered in a circular loop to produce new batteries. Over its lifetime, an average ICE car burns close to 17,000 liters of petrol or around 13,500 of diesel, if those oil barrels were stacked end to end they would make a tower 70-90m high - approximately the height of a 25 story building. On the other hand, the metals used in battery cells are around 160 kg, based on the average battery size and composition. When taking into account the recycling of the battery cell materials and that the majority of the metal content is recovered, only around 30 kilograms of metals would be lost for the 'average' battery considered (including 1.8 kg of lithium, 0.4 kg of cobalt and 1.4 kg of nickel), or the size of a football. The weight of petrol or diesel fuel that is burned during the average lifetime of a vehicle is around 300-400 times more than the total quantity of battery cell metals that are not recovered.



On the energy efficiency side, over its lifetime the BEV will require 58% less energy than a petrol car over its lifetime. With regards to CO_2 emissions, the average European BEV emits 64% less CO_2 than a conventional ICE when comparing CO_2 lifecycle emissions (see [T&E EV LCA tool](#)). In economic value, on top of being close to three times cheaper to operate, BEVs powered with renewables also produce six to seven times more useful energy for a given investment.

Our current dependency on crude oil for cars dwarfs our future dependency on battery raw materials. Although the EU is currently highly dependent on both oil imports (96% for crude oil supply) and battery raw materials (above 50% for nickel, 86% for cobalt and 100% for lithium), the dependency on oil is several orders of magnitudes higher than the one for metals, even when looking at 2035 in a scenario when all new cars are BEVs. As Europe develops some of its domestic resources, notably lithium, the dependency will decrease. Oil consumption for passenger cars in the EU27 + UK is equivalent to 1.3 billion barrels of oil which, if we imagine placing them on top of each other, would become a tower of one million kilometers in height, or close to three times the distance between the Earth and the Moon. On the other hand, the total battery demand for primary raw materials would account for around 1.1 Mt in 2030 (1.3 Mt in 2035), or a single cube 71 meters large. Looking at the economics of it, T&E calculates that in 2030, oil demand for passenger cars would still account for close to 60 billion euros, or approximately fifteen times more than the bill for battery cathode metals. Even in 2035, the EU will still spend close to ten times more on oil imports than on key battery cell materials such as nickel, cobalt, lithium and manganese.

Industrial processes linked to battery manufacturing (like all resource extraction) have their toll on the environment but if we put into perspective the battery industry with the fossil fuel one, one cannot deny that the two industries have been suffering from double standards. The oil industry has benefited for years from lax environmental and social standards, has fuelled wars and corruption and its use has caused long-lasting devastating effects in terms of climate change and air pollution. With batteries, the EU has the unique opportunity to move away from the fossil fuel industry and its environmental, social and economic legacies. This however can only be achieved sustainably if Europe invests in recycling and reuse potential, in improved chemistries that use less material, and if it utilises smartly its available resources.

Recommendations

For Europe to finally move away from burning fossil fuels in cars, it must accelerate the replacement of conventional cars with BEVs by setting an **EU-wide phase-out date** for the sale of new cars with internal combustion engines no later than 2035. Policies to use cars more efficiently, especially **shared mobility and less private car use in cities**, will reduce raw materials demand.

Whilst the new EU battery regulation takes an important step towards ensuring that EV batteries meet the highest environmental and social standards, more should be done:

- **Responsible supply chains:** mandatory due diligence requirements should be extended to copper, the list of international instruments should be being strengthened and artisanal and small scale mining must be recognised and addressed through EU development policies.
- **Carbon footprint:** ambitious and future proof maximum carbon footprint thresholds should be set. Companies should not be able to use offsets and only direct and proven use of renewable electricity should be taken into account, not fictional Guarantees of Origin.
- **Recycling:** proposed battery material recovery targets should be increased to 90% for lithium and 98% for cobalt, nickel and copper, securing future material supply and reducing dependency on mining.

At the same time, the EU should recognise the negative impacts linked to **oil extraction and its use in transport** and take action to put an end to its dependency. Subsidies going to fossil fuels as well as oil exploration and extraction in Member States' territories should be terminated. The fossil fuel industry should be mandated with the same strict due diligence standards as batteries.

Strong **EU industrial policy** has a key role to establish a resilient, innovative and clean leading European industry. First, companies will need to take a stronger foot in the battery supply chains and tighten environmental and social control. Second, the EU should aim to become a global leader on the next generation of advanced battery technology (mainly solid state batteries).

Ultimately there is no comparison between dirty oil and battery materials. Battery electric vehicles and their bill of materials is already far superior from an environmental, economic, social and efficient use of resources point of view. And with the right industrial policy and ambitious sustainability requirements in place, Europe will not only be able to electrify its fleet sustainably to reach its zero emissions goals, but also reap the benefits of the key industrial jewel of the 21st century. Combustion engines fuelled by oil dominated our lives for over a century, but the age of clean and battery-driven mobility has arrived.

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Abbreviations

BEV	Battery Electric Vehicle
BNEF	Bloomberg New Energy Finance
EV	Electric Vehicle *(In this report, this stands for battery electric vehicles and plug-in hybrid electric vehicles).*
EROCI	Energy Return on Capital Invested
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
IA	Impact Assessment
ICE	Internal Combustion Engine
IRMA	Initiative for Responsible Mining Assurance
LCA	Lifecycle Analysis
LDV	Light Duty Vehicle
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PHEV	Plug-In Hybrid Electric Vehicle
TCO	Total Cost of Ownership

1. Introduction

Emissions from the transport sector are the European Union's biggest climate problem and have been the only sector with increasing CO_2 emissions. In the EU, emissions from light duty vehicles (cars and vans) account for 14% of total emissions of CO_2 and more than half of CO_2 emissions from transport[2]. To meet the European Green Deal objective of reaching climate neutrality by 2050 and to reach the newly agreed 2030 GHG reduction target of -55% compared to 1990 levels, the EU needs to undergo a rapid transformation of its road transport system towards electric cars.

Batteries are the key technology underpinning the transition of road vehicles to zero emissions and freeing the sector from its dependency on fossil-fuels. With the European electric vehicle (EV) market growing, demand for battery production will also grow. And as battery production ramps up in Europe, so will the need for strategic raw materials present in batteries such as cobalt, lithium and nickel. The EU will import some of these raw materials and this new technology also poses some challenges but with the right policies and regulation in place the EU can make the most out of the numerous benefits of the transition to e-mobility. To achieve this, the European Battery Alliance was established in 2017 and is now at the heart of the European strategy to create its own competitive and sustainable li-ion battery value chain.

Nonetheless, there are still today some questions and myths around the environmental credentials of batteries and the reliability of a car mobility system entirely based on battery electric vehicles. This report will assess and investigate some of these questions related to batteries, in particular regarding the supposedly high requirements for raw materials to keep track with the EV growth and the interrogations around the supply of battery cells and associated raw materials in Europe[3]. The impact and benefits of a mobility system based on batteries is rarely put into perspective with the current oil-based system which we attempt to do here to underline the current double standard approach.

Therefore this paper aims to provide a comparison on a system level the resource needs of fuel powered vs battery powered cars to answer the underlying question: which one has less of an impact. The first section is the introduction, the second section analyses what are the implications of the uptake of EVs for the supply and demand of batteries in Europe in terms of battery cells, while section three looks into the supply and demand for battery raw materials. The fourth section compares the impact of an electric car running on renewables with a conventional fossil fuelled car along four different perspectives: demand for raw materials, energy demand, investment needs, and CO_2

[2] UNFCCC 2018 reporting

[3] Myths about the lifecycle CO_2 emissions of BEV compared to their ICE counterparts have been addressed by T&E in the past. Link

emissions. Section five presents the overall conclusion on our dependency towards battery raw materials and crude oil. Finally, in section six, lays out T&E recommendations on how ambitious policy can help foster a successful European battery industry.

2. EV battery supply and demand

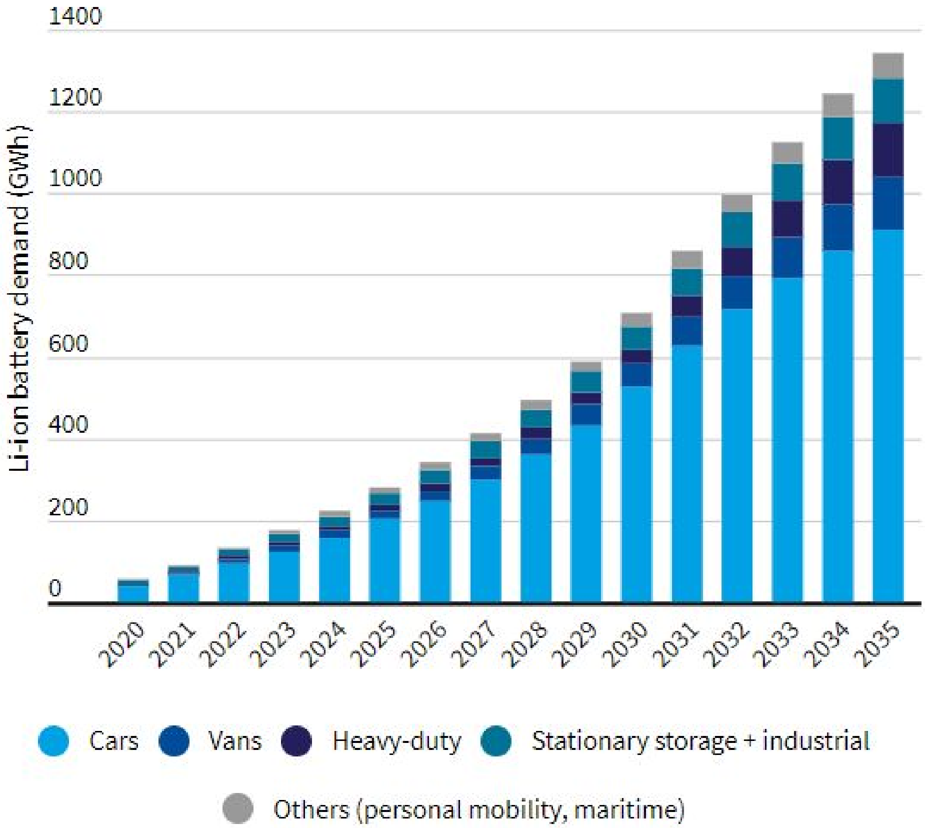
2.1 Battery demand: 700 GWh in 2030

The need for rechargeable EV Li-ion batteries in Europe will surge in the next decade as carmakers producing vehicles in Europe all transition to significantly increase their production of EVs. The amount of EVs produced in Europe in 2025 and 2030 is closely connected to the level of ambition of the European car CO_2 emission reduction targets.

The last light duty vehicle with an internal combustion engine should be sold in 2035 at the latest for the EU to respect the ambition of the European Green Deal and decarbonise road transport by 2050[4]. To be on a cost effective emission reduction trajectory, the CO_2 emissions from new cars need to drop by 25% in 2025 and 65% in 2030 (-20% in 2025 and -60% in 2030 for vans), along with additional intermediate targets .

As a result, T&E estimates that the average share of sales of BEVs would be around 21% in 2025 and 54% in 2030 (as well as 11% PHEV in 2025 and 14% in 2030), which translates into a need of 200 GWh in 2025, 525 GWh in 2030 and 910 GWh in 2035 for cars only. In Figure 1 we combine this demand for European batteries for cars with the demand from other sectors: vans, heavy-duty vehicles (both trucks and buses), industrial applications and stationary storage and other transport applications (maritime and personal mobility) for a total of 280 GWh in 2025, 710 GWh in 2030 and 1,340 GWh. The latter two categories are estimated based on data from Circular Economy Storage (CES) Online[5] while the others are T&E calculations based on the expected uptake of EVs in the EU.[6] More assumptions are provided in Annex of this report.

[4] Cars are retired on average after close to 15 years. Transport & Environment (2018), *How to decarbonise European transport by 2050.* Link
[5] Placed on the market.
[6] In this paper, we assume that the vehicles sold in the EU are produced in Europe. Some electric cars are likely to be imported and others exported but the effect of this is expected to be limited as carmakers typically manufacture the cars close to the market given that import tariffs apply and that the supply chains challenges and drawbacks of exporting cars across the globe are important. As a result we assume that the effects of the exports and the imports cancel each other.



Source: T&E modelling of vehicle sales under a Green Deal compatible scenario with focus on BEVs. In 2035, all new cars and vans are BEVs. Non-vehicle demand from Circular Energy Storage (CES) Online.

Figure 1: Forecasted battery demand in Europe

Road transport altogether accounts for a demand in li-ion batteries of 240 GWh in 2025, 620 GWh in 2030 and 1,170 GWh in 2035. Beyond 2035, the demand for batteries from light duty vehicles would increase at a slower rate as the new sales of cars and vans are fully electric and eventually stagnate around 1,400 GWh.

In the 2020s, the demand for batteries for cars stagnates at around three quarters (72%) of the total battery demand for new batteries in vehicles and storage. For vans the share of the battery demand increases from 3% of the total in 2020 to 8% from 2026. Heavy duty commercial vehicles account for

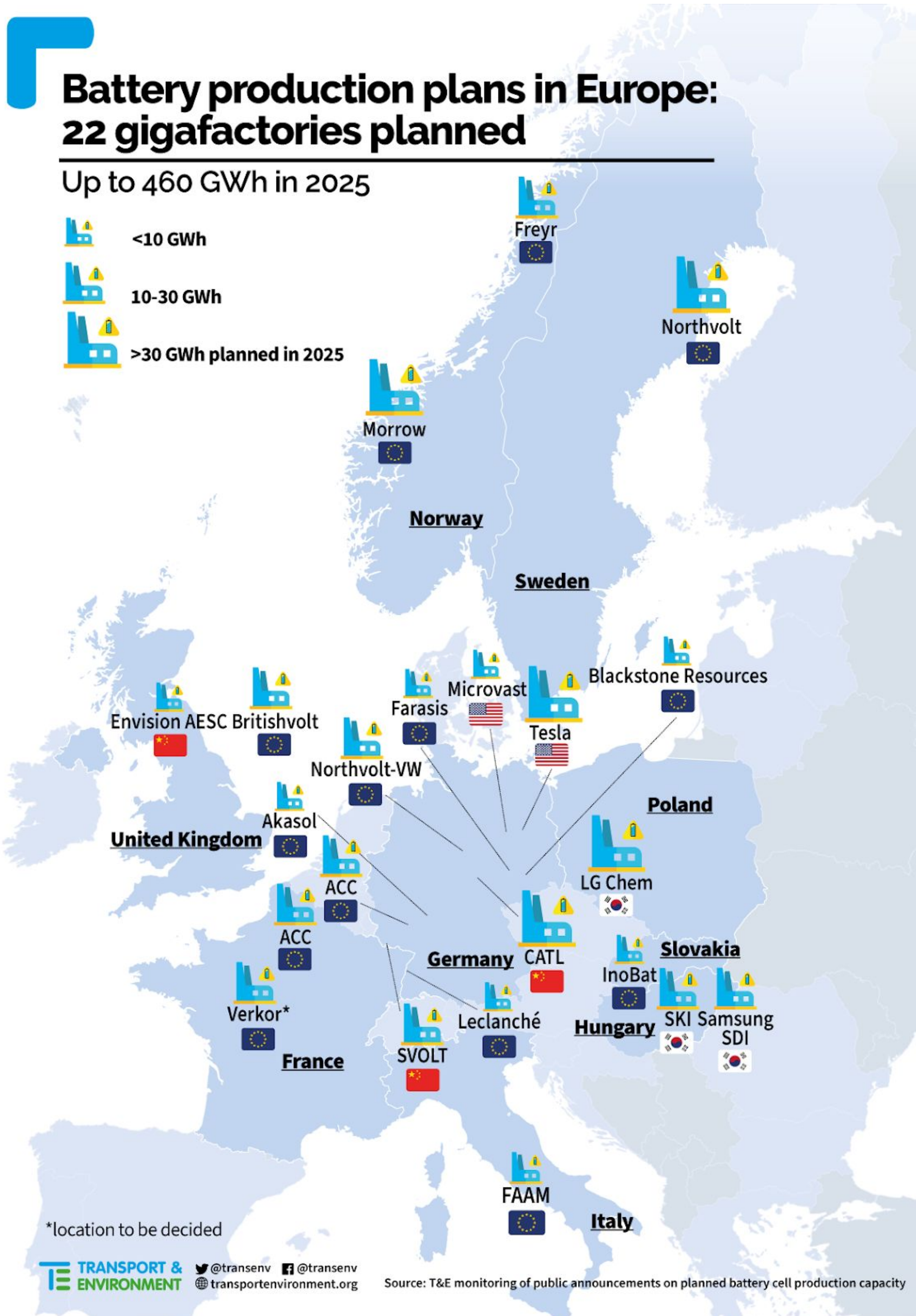
3% of the demand in 2020, increasing to 4% and only taking-off in the 2030s with 10% of the total in 2035.

2.2 European production: 22 gigafactories in the pipeline

Today, the majority of battery cells and packs are produced in Asia. With batteries being a cornerstone of EU industrial policy, investment commitments to manufacture cells across Europe are flowing. Many companies have therefore taken this opportunity to set up projects for large-scale battery production, also called battery gigafactories[7].

T&E has updated its market monitoring of the upcoming battery production projects in Europe and calculates that there are currently 22 battery gigafactories planned for the next decade, up from 14 in 2019, as illustrated in Figure 2.

[7] Production plants produce more than a gigawatt-hours of cell annually.


Battery production plans in Europe:
22 gigafactories planned
Up to 460 GWh in 2025
<10 GWh
10-30 GWh
>30 GWh planned in 2025
Freyr
Northvolt
Morrow
Norway
Sweden
Blackstone Resources
Microvast
Tesla
Farasis
Envision AESC
Britishvolt
Northvolt-VW
Akasol
United Kingdom
Poland
LG Chem
ACC
ACC
CATL
Germany
Slovakia
InoBat
SKI
Samsung SDI
Hungary
Leclanché
Verkor*
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Source: T&E monitoring of public announcements on planned battery cell production capacity

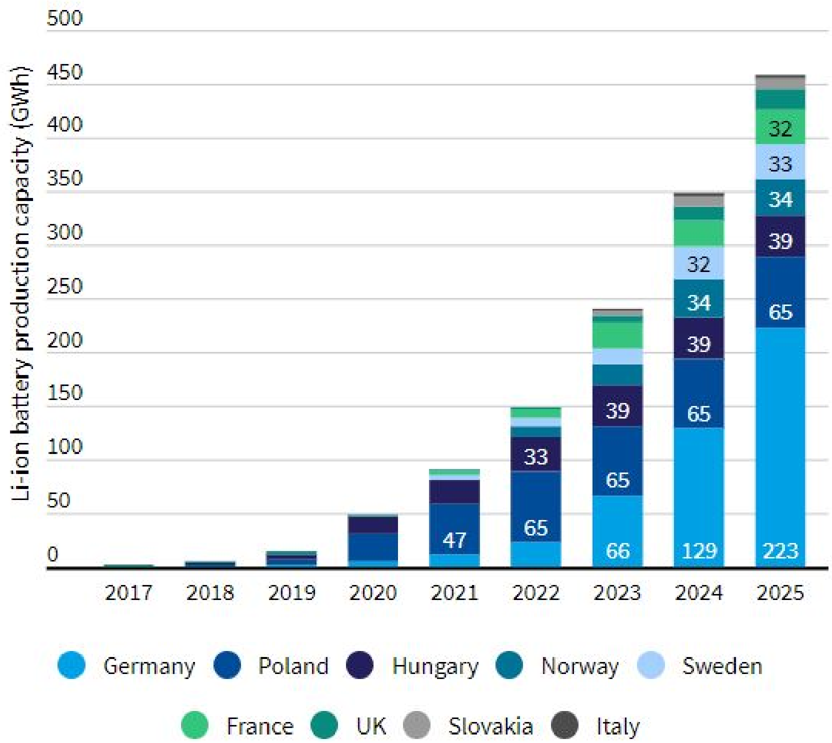
Figure 2: Map of planned gigafactories in Europe

Disclaimer: The findings in this section cover announcements and production plans up to January 2021 and therefore do not cover some of the announcements that have been made since, notably:

- *Italvolt's plans for a gigafactory in the region of Piedmont in Italy, near Turin (45GWh)[8];*
- *Northvolt plans for a new factory in Gdańsk, Poland for an initial annual output of 5 GWh in 2022, and potential future capacity of 12 GWh[9];*
- *Valencian Battery Alliance, led by Power Electronics plans for a gigafactory in Spain (Valencia region) in which 23 companies will participate, among which is Ford[10].*

These will account for an estimated capacity of 460 GWh in 2025. For comparison the production capacity in 2020 was 49 GWh[11], as shown in Figure 3[12]. Beyond 2025, there are much higher uncertainties on the scale of expected battery cell production capacity given most announcements are limited to a timeframe of several years. Nonetheless, based on what has been announced today T&E calculate an expected 730 GWh in 2030. This includes, for example, the claim from Elon Musk, Tesla's CEO, that the Berlin plant could possibly be the largest battery cell plant in the world, going to 250 GWh[13], and thus accounting for close to all of the growth beyond 2025. It is likely that other battery makers will also increase their ambition level further into the 2020s.

[8] Electrive, 18/02/2021, Italvolt to set up 45 GWh cell production in Italy. Link
[9] Northvolt, 19/02/2021, Northvolt expands operations in Poland to establish Europe's largest factory for energy storage solutions. Link
[10] Motorpassion, 18/02/2021, ¡Es oficial! Valencia tendrá una gigafactoría de baterías para coches eléctricos gracias a una macroalianza, con Ford incluido. Link
[11] European Investment Bank (2020), *EIB reaffirms commitment to a European battery industry to boost green recovery*. Link
[12] A number of projects were not included given they have not been fully confirmed, namely a Panasonic factory in Norway, a BYD European factory and the Customcells factory in Germany, in partnership with Porsche.
[13] Electrek, 24 November 2020, Tesla's first full battery cell factory will produce up to 250 GWh — roughly the current world capacity. Link

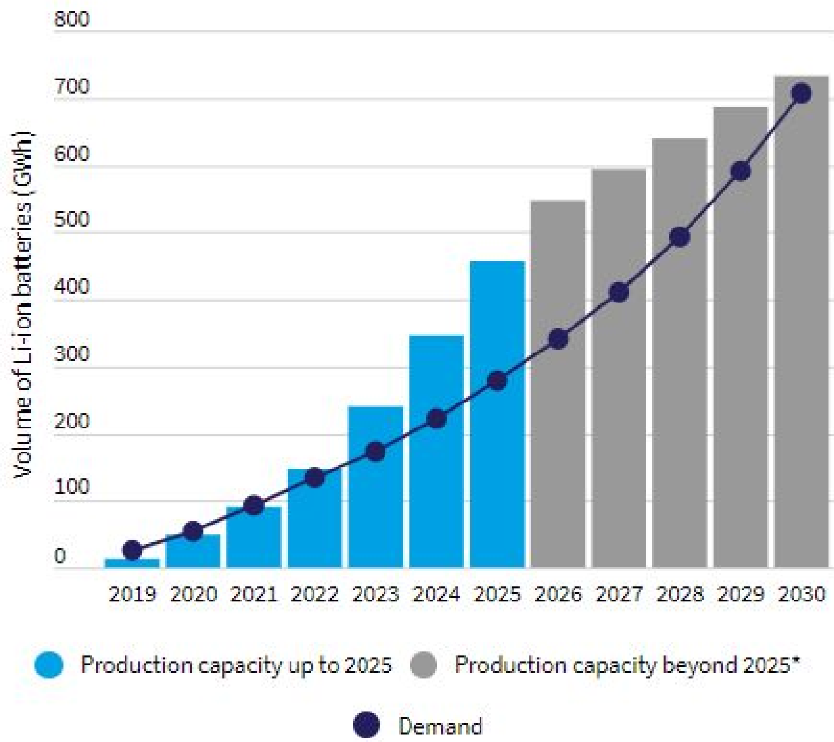


Source: T&E monitoring of market announcements

Figure 3: Battery cell production capacity in Europe, per country

Currently there is a shortage of batteries produced in Europe to equip all the electric vehicles placed on the European market. In 2020, T&E estimates the supply delivered to the market to be around 49 GWh (also confirmed by the EIB[14]) while the calculated demand is 54 GWh (40 GWh for passenger cars alone). In 2021, T&E models that both supply and demand should be on par at 91-92 GWh, assuming the planned European production ramps up on schedule. From this year, the supply overtakes the demand and reaches a maximum excess of around 200 GWh in 2026. From 2026 to 2030, this gap decreases and closes in 2030, where the calculated excess supply compared to the demand for European production is close to 30 GWh (730 GWh production capacity).

[14] EIB (2020, May 19), *EIB reaffirms commitment to a European battery industry to boost green recovery* Link



*Beyond 2025, the expected battery cell production capacity is more uncertain given most announcements are limited to a timeframe of several years.
Source: T&E monitoring of market announcements and T&E modelling of expected battery demand. Scope: EU27 + UK

Figure 4: Battery cell supply and demand in Europe

Given the uncertainties in such prospective analyses and the complexity of the large industrial projects considered here, it is possible that some of the planned European production is delayed by several years. This would push some of the production planned in the mid-2020s towards 2030 and put the supply closer in line with the demand. If the electrification of various transport and power sectors would move faster than expected, this could also easily absorb the potential excess in battery production. Furthermore, any excess in production of batteries in Europe could be exported as batteries or as electric vehicles to other markets and battery production plants could also be functioning at a capacity which is not 100%. Finally, this analysis also shows that, if battery producers deliver on their ambition, there is room to accelerate the EV sales beyond the T&E scenario and increase the car CO_2 emission standards further in the mid-2020s.

The ambition of the Europe Commission and the European Battery Alliance, is to have 15 gigafactories in Europe offering enough battery cells by 2025 to power six million electric cars (around 360 GWh)[15]. Based on the T&E monitoring of current battery production intentions, the EU could be around 100 GWh above this target if the planned gigafactories come on schedule.

Breakdown per country

Germany is by far the country which is expected to produce the most batteries in Europe with around half of the European batteries produced there from 2025. Second comes Poland with 14% of the European production in 2025 (LG Chem), while Hungary (Samsung SDI, SKI Innovation), Norway (Morrow and Freyr), Sweden (Northvolt) and France (ACC and Verkor) all reach approximately the same level with around 7%-8% of the production in 2025. Many of the production locations, especially in German are located close to vehicle production to fit into the 'just-in-time' manufacturing model of the automotive industry.

Industry and jobs

Production of Li-ion battery cells is a key industrial opportunity to prevent Europe from relying on foreign battery cell manufacturing which would ultimately negatively impact the competitiveness of European vehicle producers and expose EU industry to global supply shocks and fluctuations. Producing batteries within the European Union also guarantees that more value is retained from the overall e-mobility value chain, and thus securing the new supply chains and creating new jobs. With 460 GWh produced annually in 2025 and 730 GWh in 2030, this means there would be around 64,000 new direct jobs in battery cell manufacturing in 2025 and 100,000 in 2030. Furthermore, according to announcements and plans currently available for battery production capacity in Europe, domestic European manufacturers could take over Asian ones in 2026 for European cell manufacturing (see more in Annex).

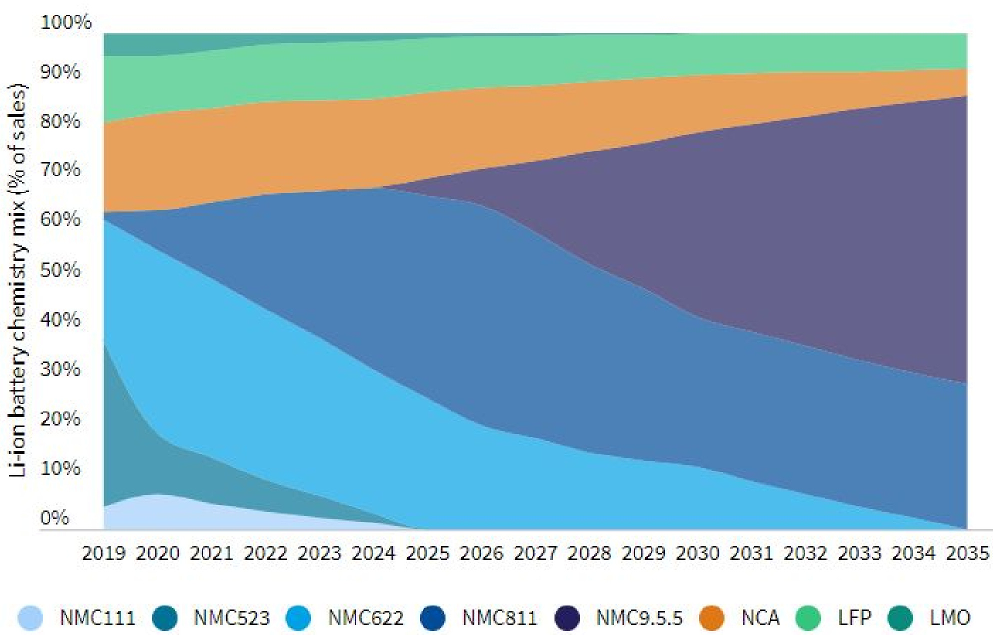
3. Raw material supply and demand

3.1 Demand for raw materials

With the increasing demand for batteries produced in Europe to supply the electric vehicle market comes an increasing demand for raw materials. In this section T&E modelled the expected demand for Li-ion battery cell raw materials, chiefly nickel, lithium, cobalt and manganese and takes into account the total amount of battery supply required (section 2.1), the expected evolution of the battery chemistries, their energy densities and the detailed composition of each of these chemistries.

[15] Speech by Vice-President Šefčovič at the European Conference on Batteries. Link

Firstly, based on several sources (including BNEF and Ricardo[16]), T&E elaborated a scenario for Li-ion battery chemistry mix which will be used to power the electric vehicles. The dominant chemistry today is NMC622, accounting for 36% of the batteries on the market, which would be overtaken by NMC811 in 2025 (41% of batteries) and then by NMC9.5.5 in 2030 (37% of batteries), as per Figure 5 below. The naming convention for battery chemistries is based on the first letter of the key materials included in the cathode, along with their proportions. For example the cathode of NMC622 batteries is made of nickel, manganese and cobalt in the proportions 6-2-2 (i.e. three times more nickel than manganese or cobalt). As we approach 2030, it is expected that batteries will move from Li-ion to advanced chemistries (see info box on p.26), which leads to much higher uncertainties with regards to the battery mix, especially after 2030.



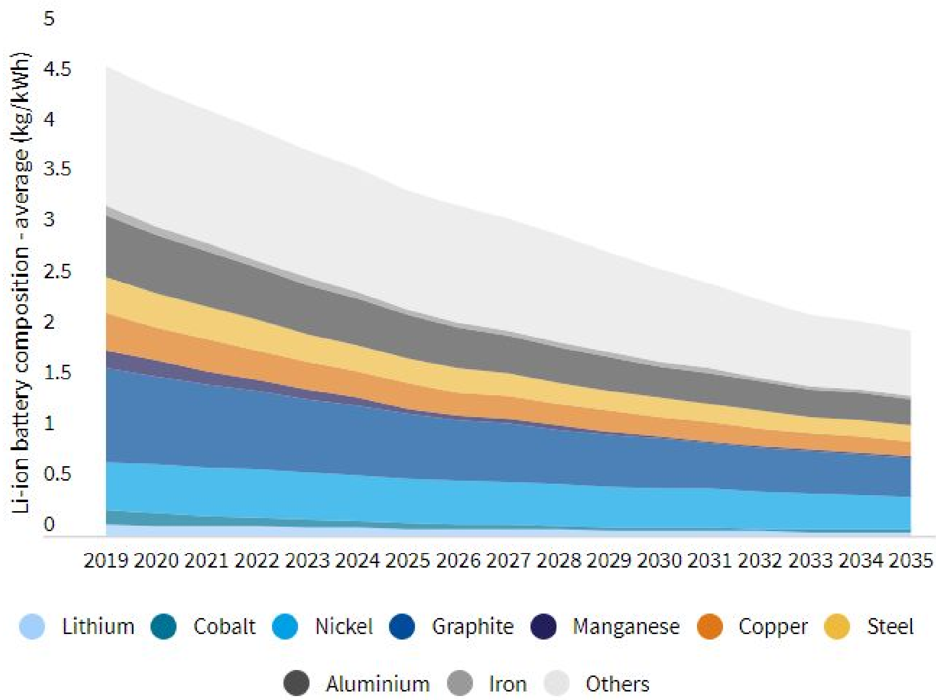
Source: Combination of BNEF, Ricardo and author's assumptions

Figure 5: Average battery sales composition

Thanks to an increase in battery energy density (from slightly more than 200 Wh/kg in 2020 to around 350 Wh/kg in 2030), each of the battery chemistries presented above will require less material for a given kWh over the years. By taking this into account, T&E calculates that the amount of lithium

[16] Ricardo, Link. BNEF, Link

required for a given kWh of battery decreases from 0.10 kg/kWh in 2020 to 0.05 kg/kWh in 2030 (see Figure 6, see more in Annex)[17]. For cobalt the decrease is even more significant with battery chemistries moving towards lower contents of cobalt: from 0.13 kg/kWh in 2020 to 0.03 kg/kWh in 2030. For nickel the decrease is less pronounced as NMC batteries move towards higher nickel content: from 0.48 kg/kWh in 2020 to 0.39 kg/kWh in 2030.



Source: Combination of various sources, including BNEF, Ricardo and author's assumptions
Others include mainly the electrolyte, binder and separator

Figure 6: Average battery cell composition (kg/kWh)

From hereon, the rest of the section will focus on three key raw materials: nickel, cobalt and lithium, due to their prominence both in battery technology and importance from a policy and strategic sourcing point of view.

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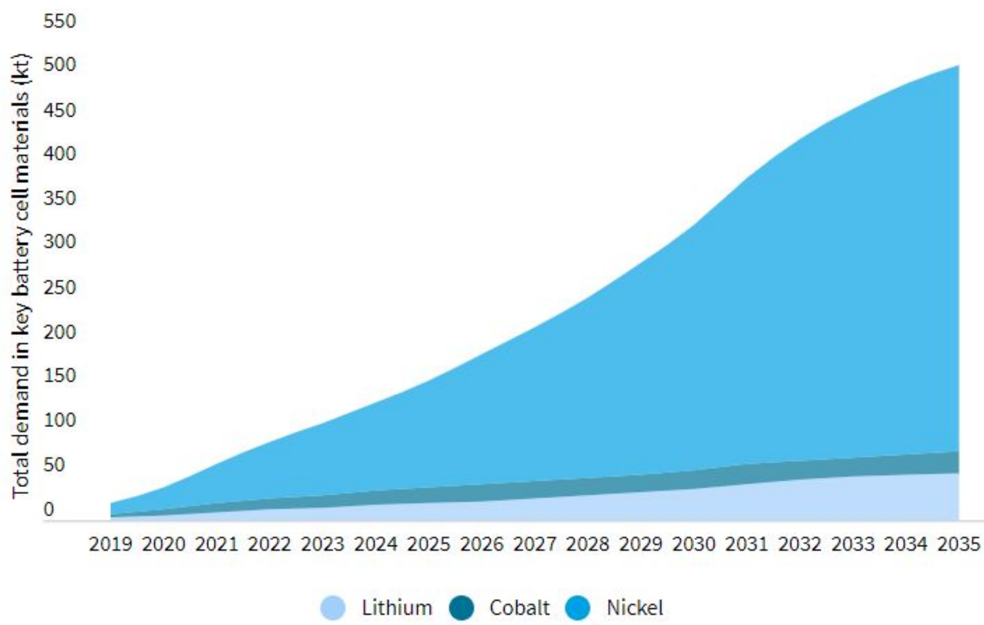
[17] Excluding waste during manufacturing, formation cycle loss and inactive active material (material in the cathode that is not in electrical contact with the current collector).

By combining the results above, T&E modelled the total volumetric demand in key battery cell raw materials (nickel, lithium, cobalt and manganese) and calculated the raw material demand for these metals. The demand for materials from the planned European production will significantly increase (see Figure 7):

- from 5 kt of lithium in 2020 to 36 kt in 2030;
- from 7 kt of cobalt in 2030 to 21 kt in 2030;
- from 26 kt of nickel in 2025 to 276 kt in 2030



Source: T&E modelling. Supply from recycled material is excluded

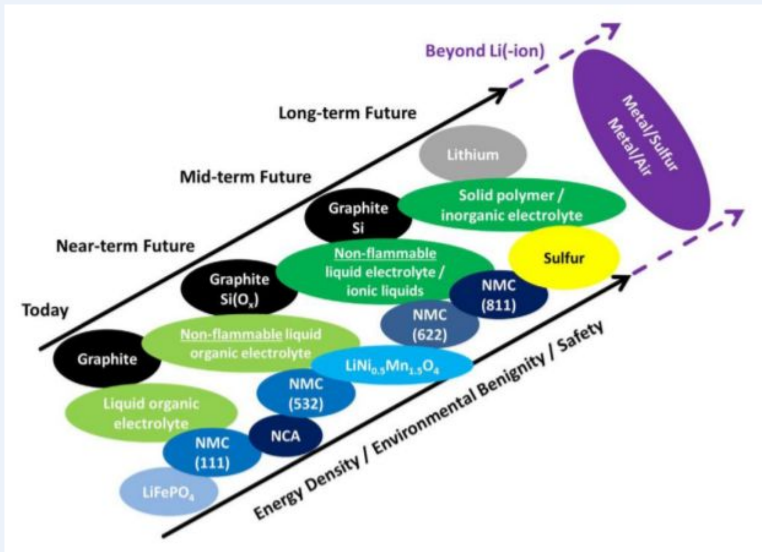
Figure 7: Total demand in key battery cell raw materials without recycling (in kt)

There are important uncertainties underlying the evolution of raw material demand for battery cells, with the evolution of the battery chemistries playing an important role. In particular, it is very challenging to foresee and model any breakthroughs in battery cell chemistries.

The current analysis is based on incremental evolution of current known battery chemistries and does not take into account the potential penetration of advanced battery chemistries because of the inherent uncertainties. As a result, the output presented here for the 2030-2035 timeframe should be considered for indicative purposes only. More information on future more advanced battery chemistries can be found in the info box below.

Info box: Advanced battery chemistries

Liquid-electrolyte batteries



Graphite-based anodes are currently being incorporated with increasing amounts of silicon in order to improve the energy density (traditional graphite anodes have rather poor energy densities). However as silicon anodes absorb a large number of lithium ions during charging, the battery swells causing its surface to crack and energy storage performance to drop rapidly. This is currently being solved by replacing only around 10% of the graphite in a battery anode with silicon metal oxide, thus improving density without introducing too much swelling. In the mid-term future, the silicon content in graphite anodes is expected to continue to rise rapidly (Si/C anode), see image above[18].

Solid-state batteries

A solid-state Li-ion battery is a battery technology that uses a solid electrolyte, instead of the liquid or polymer gel electrolytes. Materials proposed for use as solid electrolytes in solid-state batteries include solid polymers (or organic), hybrid solid electrolytes and ceramics (or inorganic, e.g. oxides, sulfides, phosphates). According to a recent report commissioned by the EU Commission[19], the former has been demonstrated and produced on a small scale[20] while the second is in applied research and the latter in the basic research stage.

The most promising anode is the lithium-metal anode but such anodes tend to suffer from the

[18] D. Bresser et al. (2018), *"Perspectives of automotive battery R&D in China, Germany, Japan, and the USA"*, J. Power Sources, vol. 382, pp. 176–178.
[19] European Commission (2020). *Solid-state-lithium-ion-batteries for electric vehicles.* Link
[20] The solid-polymer-electrolyte batteries will be at the stage of 'market introduction with competitive performance indicators' from 2025 (TRL: 7-8).

formation and the growth of lithium dendrites[21], which is today one of the biggest challenges with solid state batteries. By enabling these lithium anodes, solid state batteries are able to achieve much higher densities. Cathode materials could be composed of traditional NMC and NCA cathode materials but are expected to shift to next generation cathodes like sulphur[22].

Solid state batteries could be expected from the second half of the 2020s[23], and would have reduced costs and very high energy densities: around 350-500 Wh/kg (vs. around 200-250 Wh/kg currently), 800-1,200 Wh/L and 1,000 cycles before reaching end-of-life. BloombergNEF expects that these cells could be manufactured at 40% of the cost of current lithium-ion batteries, when produced at scale[24]. Although there are still considerable R&D challenges, solid state batteries are on the roadmaps of most major Li-ion battery producers and OEMs (with many aiming to get into the market with solid state battery EVs between 2022 and 2025, see more in Annex).

Metal-air chemistries

Finally the last of the currently foreseen steps in the battery technology breakthroughs are lithium-air (Li-air) -or other metal-air- batteries with a more uncertain time frame (possibly from the early 2030s) with an energy density of 500-700 Wh/kg[25].

3.2 Supply of raw materials

3.2.1. Supply from recycled EV batteries

The supply of raw materials will be a significant task in the coming years as battery demand grows fast. This supply must be ramped up in the most effective and sustainable way to limit the impact on the environment and land use as much as possible. To achieve this, it is key to prioritise the use of recycled, or secondary, materials to decrease the amount of new primary sources, or mining, as well as strengthen the security of the supply of materials and safeguard from price volatility. High recovery targets for the battery raw materials should be at the heart of this circular economy strategy. Reuse of used batteries (either for stationary storage or for less demanding mobility applications) also removes some of the pressure to build new batteries with extra virgin materials.

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[21] Dendrites are crystals that develop with a typical multi-branching tree-like form (e.g. snowflakes). With lithium anodes, dendrites penetrate the separator between the anode and the cathode causing short circuits, which may result in fire and maybe even explosion.

[22] Sulfur makes an unsuitable cathode in liquid electrolyte applications because it is soluble in most liquid electrolytes, dramatically decreasing the battery's lifetime.

[23] European Commission (2020), *Solid-state-lithium-ion-batteries for electric vehicles.* Link

[24] BloombergNEF (2020), *Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at* $137/kWh. Link

[25] PushEVs (2020, June 10), *CATL Energy Density Development Roadmap.* Link

Higher recycling targets

Recycling waste batteries keeps raw materials in use for longer periods, by recovering valuable materials, using them for new products and preventing losses. This is especially the case for critical metals used in batteries, notably cobalt and lithium. The European Commission's new proposed regulation on batteries has specific recycling targets for lithium-ion batteries which are: 90% for cobalt, nickel and copper in 2025, then 95% in 2030; and 35% for lithium in 2025 and 70% in 2030, see infobox below.

Info box: New EU battery recycling targets[26]

The European Commission's new proposed regulation on batteries has specific recycling targets for lithium-ion batteries. These targets mandate a recycling efficiency (ratio between the weight of recycling input and recycling output)[27] of 65% by 2025, and of 70% by 2030 based on weight.

Moreover, the proposal asks for specific recovery rates for cobalt, nickel, lithium and copper:

Recovery rates	Co, Ni, Cu	Li
2025	90%	35%
2030	95%	70%

Further to this, the Commission is also requiring new batteries to have a minimum recycled content as of 2030 as follows:

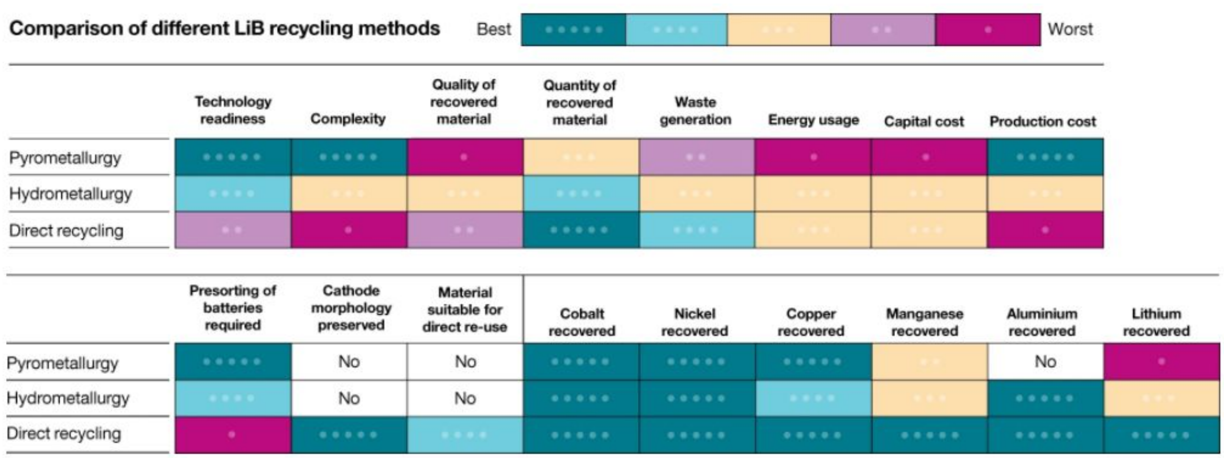
Recycled content	Cobalt	Lithium	Nickel
2030	12%	4%	4%
2035	20%	10%	12%

The Impact Assessment (IA) of the European Commission for the battery proposal mentions that the 2025 material recovery targets can be met with the current recycling efficiency for lithium batteries (50%) while the 2030 material targets could only be met if recycling efficiencies increase. On the other hand the available literature shows that higher material specific recovery rates are possible.

[26] Taken from Commission draft proposals from December 2020, yet to to be agreed in co-decision to become final law.
[27] Recycling efficiency is the ratio between the weight of recycling input and recycling output.

For **lithium**, a 2019 study looking into recycling for mobile phones[28] has shown that the efficiency of the processes varies from 76% to 95% of lithium being recovered, with most recovery ranges reaching at least 90%. Thanks to better disassembly methods, the recovery rates from battery recycling can greatly improve. Indeed, the direct recycling method performs much better on lithium recovery than the other processes (pyrometallurgy and hydrometallurgy), see below Figure 8 from the aforementioned paper. Such technological and industrial progress makes a 90% recycling target for lithium in EV batteries a much more adequate target than the current 70% target proposed[29]. For **cobalt**, the same paper states that extraction yields were in the range of 97–99%.

In China, the official guidance for companies to receive government funding and support (not binding legislation) asks companies to recover 98% of cobalt and nickel and 85% of lithium[30]. Despite it not (yet) being binding, companies who do not fulfil the requirements will not receive the government support they otherwise would, neither on state level nor on provincial level. According to expert Hans Eric Melin most recyclers are already complying.


Comparison of different LiB recycling methods — Best ••••• •••• ••• •• • Worst

	Technology readiness	Complexity	Quality of recovered material	Quantity of recovered material	Waste generation	Energy usage	Capital cost	Production cost
Pyrometallurgy	•••••	•••••	•	•••	••	•	•	•••••
Hydrometallurgy	••••	•••	•••	••••	•••	•••	•••	•••
Direct recycling	••	•	••	•••••	••••	•••	•••	•

	Presorting of batteries required	Cathode morphology preserved	Material suitable for direct re-use	Cobalt recovered	Nickel recovered	Copper recovered	Manganese recovered	Aluminium recovered	Lithium recovered
Pyrometallurgy	•••••	No	No	•••••	•••••	•••••	••	No	•
Hydrometallurgy	••••	No	No	•••••	•••••	••••	•••	•••••	•••
Direct recycling	•	•••••	••••	•••••	•••••	•••••	•••••	•••••	•••••

Figure 8: Comparison of different recycling methods[31]

However, the impact assessment does not consider any higher targets than the ones proposed in by the Commission in December 2020 and does not justify why the proposed rates are chosen.

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[28] D. Quintero-Almanza et al., (2019), *A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective*. Link
[29] Nature, Recycle spent batteries. *Nat Energy* 4, 253 (2019). Link
[30] Chinese official guidance for government funding and support. Link
[31] G. Harper et al., (2019). *Recycling lithium-ion batteries from electric vehicles.* Link

In the analysis below, and given the evidence to date, the T&E scenario for recycling will be **90% for lithium and 98% for cobalt and nickel** (see recommendations for more). It should be noted that battery chemistries in particular of Li-ion may change comparatively fast therefore specific recovery targets should be prioritised before and above the recycled content requirements. But it is important that only high-quality recycling should be accounted for material recovery targets (no down-cycling), in order to ensure that these recycled battery materials are able to feed back into the battery value chain.

Cost-effectiveness of recycling: Higher recycling targets might not be fully economically viable in the early phase (e.g. with current lithium recycling) but they will drive the market and investment into the European recycling industry. As investments are made and technology improves and scales, then higher targets will be economically viable. Furthermore, it's the value of the metals that is driving the recovery rate, which means that the actual recovery rates are likely to be higher than the targets from the regulation given the recycling will have to be fulfilled at a high level already.

Battery casing and periphery: In order to cover the remaining materials, not covered by the specific recycling targets, there is a target of overall battery recycling of 65% by 2025, rising to 70% by 2030 based on weight. Due to the high economic value of the aluminum and copper in the outer casing and periphery of EV batteries, the recycling of these materials is likely to be driven by the market to a large extent. It should be noted that recycling of outer casing and periphery account for about 30% (due to aluminium recycling) of the entire credits of Global Warming Potential (GWP) from battery recycling according to the European Commission.

Environmental benefits from recycling: Due to the high relevance of the active materials (e.g. cobalt) specific targets for the recovery of these materials are considered to be necessary. The impact assessment shows that setting targets for material recovery rates for specific materials (Co, Ni, Li, Cu, Pb) leads to higher environmental benefits. According to the European Commission Impact Assessment, there would be an overall CO_2 reduction of 4.3% (all emissions from battery production, includes the upstream) from a small increase in the recycling target: from 80% for cobalt, nickel and copper and 10% for lithium (baseline scenario) to what is proposed by the European Commission[32]. Similar results are found for the depletion of abiotic resources and human toxicity potential.

T&E analysis on recycling focuses on three of the key battery materials which are regulated with specific material-recovery targets: lithium, cobalt and nickel. Copper is also partly covered as well because of a similar recovery target.

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[32] About 150 000 (in 2020) to 620 000 metric tons (in 2030) of CO_2-eq are avoided every year compared to the baseline.

Impact on the reduction of battery materials demand

Thanks to recycling, a significant share of the battery raw materials can be recovered as secondary material and be used again in the value chain, thus reducing the overall material demand for primary materials. Figure 9 below presents an overview of how much lithium, cobalt and nickel is consumed for an average BEV battery, both in 2020 and 2030. First, the material requirements per battery production are calculated, then compared with the amount of battery material which is not recycled - and which can be considered as 'lost' (or 'consumed') in the process - under two recycling scenarios; current targets proposed by the European Commission (EC) and T&E recycling targets. Calculations are based on the above assumptions for the material content of battery cells for a 60 kWh battery.

For vehicles produced with the average 2020 batteries, recycling the battery reduces the amount of key battery cell material (lithium, cobalt and nickel) lost by 92% under the targets of the European Commission and 97% under the T&E targets. In other words, compared to a scenario with no recycling, there is a loss of 8% of the materials necessary under the European Commission target, while it drops to 3% under the T&E target. Thus, **increasing the ambition from the EC recycling target to the T&E recycling targets reduces by two thirds the quantity of lithium, nickel and cobalt lost**. For batteries produced in 2030, the same relative benefits of the T&E recycling targets over the current EC recycling targets can be found, however, the volumes of metal lost are lower thanks to improvements in battery chemistries (see Table 1 and Figure 9 for more details).

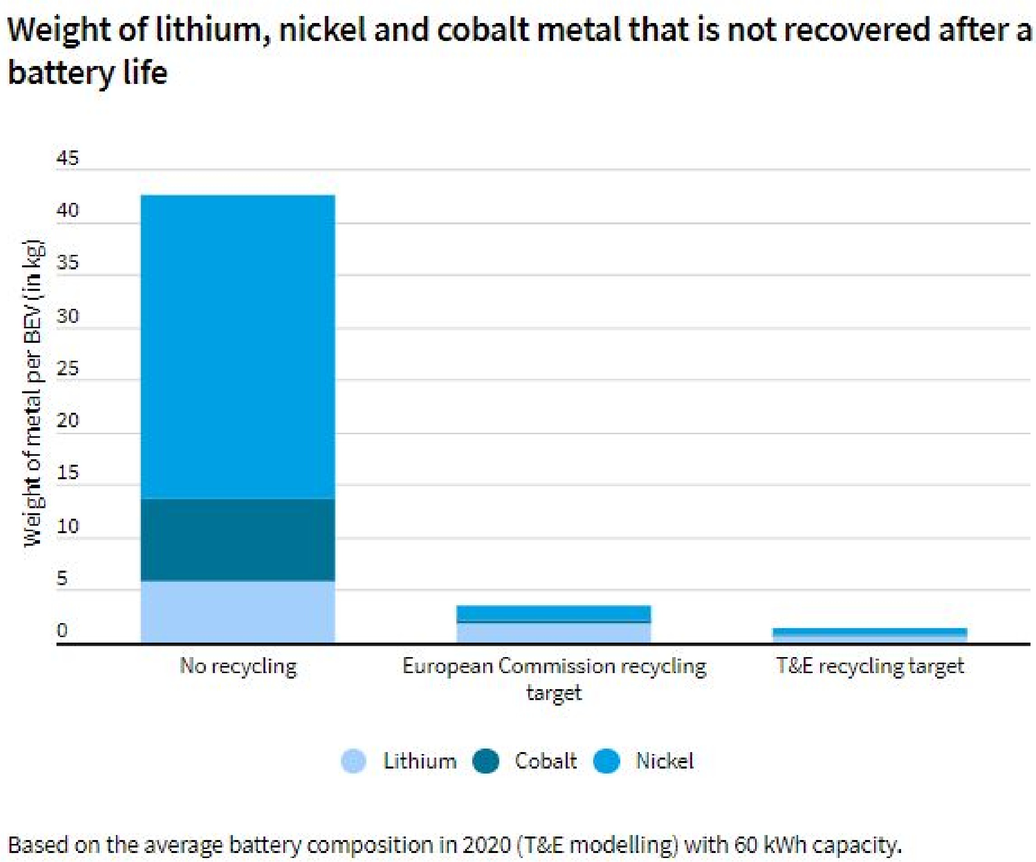

Figure 9: Comparison of metal-weight consumption in different scenarios

This means that in the long run, when ICEs are fully phased out and the high volumes of EoL batteries go to recycling, the T&E recycling targets would **reduce by a factor of three the amount of primary lithium required** to make new batteries and by **2.5 the amount of nickel and cobalt** compared to the current European Commission proposed targets.

Minerals	No recycling		EC recycling target		T&E recycling target	
	2020	2030	2020	2030	2020	2030
Lithium	5.9 kg	3.1 kg	1.8 kg	0.9 kg	0.6 kg	0.3 kg
Cobalt	7.7 kg	1.7 kg	0.4 kg	0.09 kg	0.2 kg	0.03 kg

Nickel	28.9 kg	23.5 kg	1.4 kg	1.2 kg	0.6 kg	0.5 kg

Table 1: Key metal 'lost' per average BEV battery

Securing raw material though recycling

Batteries which are available for recycling mainly come from EV batteries that have reached their end of life in the vehicle (or end of second life in secondary application) but they can also originate from: batteries from production scrap, from test batteries/EVs, off-spec products, non-sold batteries (return-to-vendor) vehicles, road accidents and any type of battery replacements. As a result, EV batteries that go to recycling can have the material composition of batteries that are produced in the same year, or can be much older. Therefore, flows of EV batteries that go back to recycling companies will stay small in the next decade as the EV batteries will last more than a decade on average in their first use for transport (for the vast majority) while second-life applications and battery re-use will further increase the lifetime of a battery until the moment the battery reaches the final recycling stage. However, because of production scrap and earlier replacements, materials used to produce batteries are expected to find their way back to the recycling stage after slightly more than 10 years on average.

According to Circular Energy Storage, in 2030, only 16% of the global 170 GWh end-of-life batteries (i.e. 27 GWh) will be available for European recyclers[33], which is only 4% of the overall European battery demand in 2030. Given the low volume of EVs sold before 2020, the availability of EV batteries for recycling will only start to increase to more significant levels towards the early 2030s when the EV batteries from early EVs reach the recycling stage. When modelling the recycling capacity beyond 2030, T&E calculates that European recyclers could provide materials for up to 16% of new cells manufactured in 2035, or around 220 GWh. The supply from other sources of batteries like portable electronics - which are not taken into account here - will also contribute to the secondary supply of recycled content, especially in the 2020s when the supply from EV batteries is still relatively low.

T&E calculates that the amount of recycled material from EV batteries will increase sharply in the 2030s: supply of recycled lithium would increase from around 2,000t in 2030 to 12,000t in 2035 (contained lithium, not LCE or lithium carbonate equivalent); supply from recycled cobalt from 4,000t in 2025 to 16,000t in 2035 and supply from nickel from 11,000t in 2030 to 94,000t in 2035 (see Figure 10). In the T&E scenario, the total amount of recycled lithium, cobalt and nickel increases by 6% compared to the European Commission targets.

This supply from recycling reduces the pressure on the primary demand for raw materials and the need to provide supply from mining activities. In 2030, 5% for lithium, 17% for cobalt and 4% for nickel

[33] 'PV-magazine, December 16, 2020. *Europe's battery recycling quotas are blunt and a decade too late'* Link

required for new EV battery production can be obtained from recycled European EV batteries (based on the European Commission material recovery rates). In 2035, recycling could provide at least **22% of the lithium and nickel** and **65% of the cobalt** necessary for European EV battery production (28% for lithium, 22% for cobalt and 67% for nickel under the T&E scenario). These calculations conservatively assume that 2035 EV batteries are still based on the liquid electrolyte batteries (mainly high density NMC) and do not take into account the likely uptake of more advanced battery chemistries. In other words, if recycling was not taken into account, other supply sources would need to ramp-up, including primary sources from mining and secondary supply from other regions. For example, in 2035, the supply of cobalt would have to triple in the absence of recycling (+28% nickel and +39% lithium).

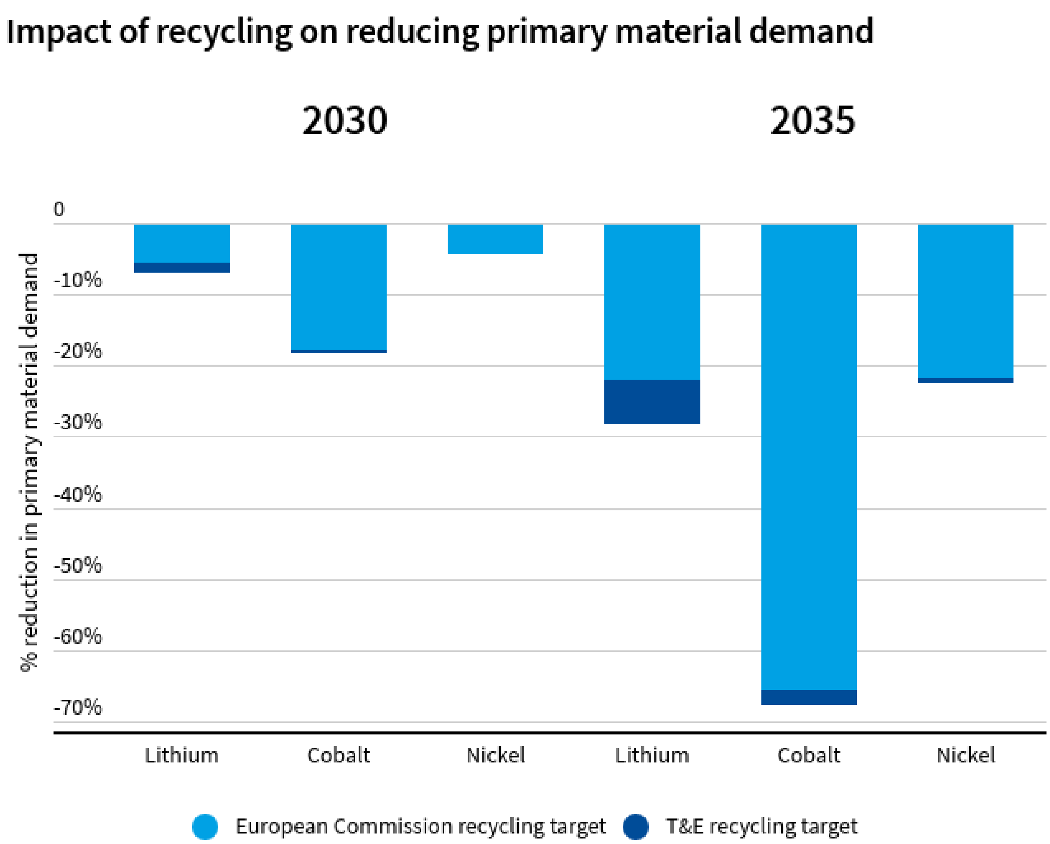

Figure 10: Impact of recycling on reducing primary material demand

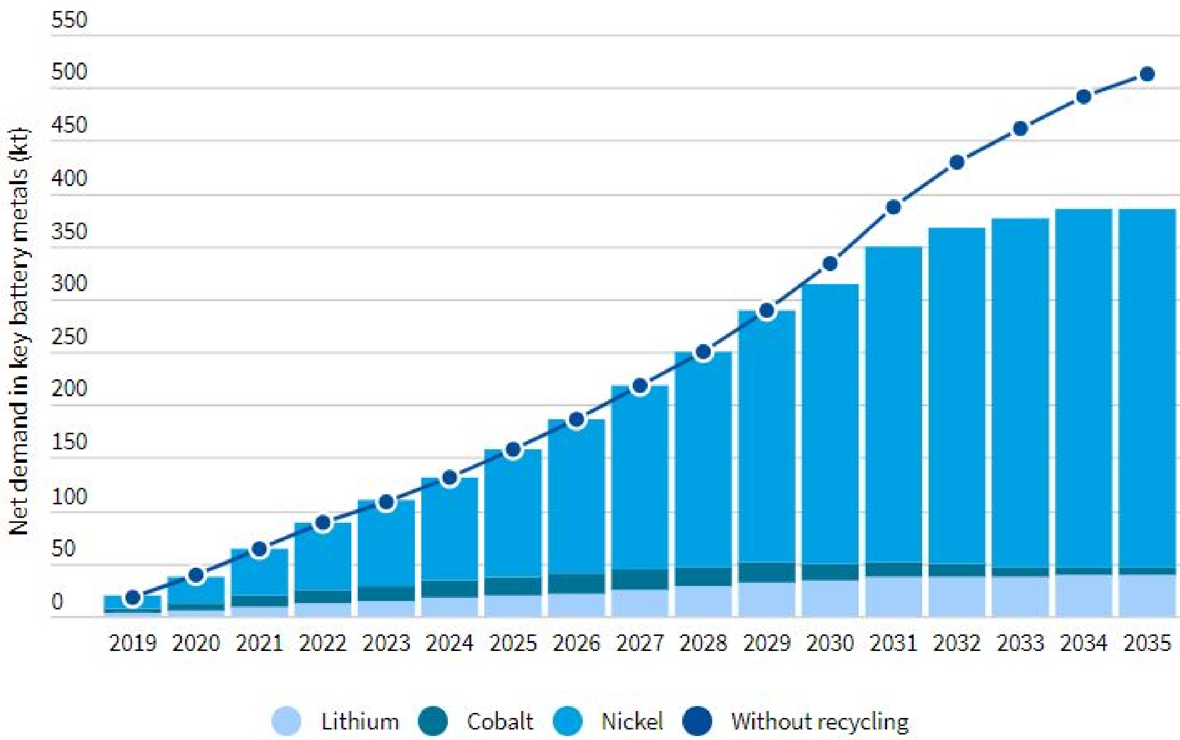

Figure 11: Demand of Li, Ni and Co, including supply from recycling

The supply of recycled materials from portable electronics is not part of the scope of this analysis. If we were to take this secondary supply into account, this would provide secondary metals much sooner and result in lower net demand from primary sources as a consequence of higher supply from recycling (due to shorter useful life of these cells). Nonetheless, supply from (recycled) portable batteries is much smaller than from EV batteries (at least by a factor 10), and cannot replace recycled EV batteries.

The European Commission also proposed targets for recycled content of 12% for cobalt and 4% for lithium and nickel[34], although that target does not specify the origin of the recycled content[35].

[34] It this report, it was assumed that when taking into account the various sources of end-of-life EV batteries available to recycling (e.g. production scrap, degraded battery etc..) and averaging the effects, the amount of EV batteries available for recycling in battery in a given year is equal to the volume placed on the market 11 years prior to that year.

[35] Recycled batteries from portable electronics can be used to reach the recycled content target. As reported by article from PV-magazine, even in 2030, most batteries available for recycling will come from portable electronics and EVs will contribute only 26% of volume.

However, because the battery market is a fast growing and highly innovative one and there are inherent uncertainties on the type of batteries produced in the future (especially from 2030), high recycling targets should be preferred over more uncertain and redundant recycling content targets. For example, LFP batteries have recently made an come-back as they are becoming increasingly popular for cheaper mid-sized EVs although they have inferior energy densities. If this trend continues, and because LFP batteries do not contain cobalt, then cobalt recycled content targets become useless for LFP batteries (and very easy to reach for the remaining batteries that use cobalt). On the other hand, as high-lithium content solid state batteries take over the market, the target for lithium recycled content could become more challenging.

3.2.2 European battery recycling industry

European recycling: market overview

Up to recently, the European battery recycling market has been driven by the compliance with the EU Battery Directive from 2006 which covered all kinds of portable batteries including single-use and rechargeable chemistries and lithium-ion batteries have played a marginal role compared to other chemistries (mainly because they are built in portable devices).

In 2019, recycling capacity in the EU was around 33,000 tonnes per year with 15 battery recycling companies[36]. Europe's leading battery recycler, Umicore[37], has 7,000t of capacity while the second largest recycler, Veolia, has a capacity of 6,000t in their Euro Dieuze plant (including 2,000 for EV batteries and has a contract for recycling Renaults' EV batteries). Next come three German companies which only do pre-processing (no material recovery); Accurec and Duesenfeld with a 3,000t capacity and Redux with 2,500t capacity.

Moreover, the European recycling capacity has not been fully utilized according to the experts, as only 18,200 tons of waste batteries were recycled in Europe, or 59% utilization of the EU recycling capacity. This low utilization could partly be explained by the factor that 17,900 t of batteries were exported outside of the EU because of complex technical implications and high costs.

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[36] Transport & Environment (2019), *Batteries on wheels: the role of battery electric cars in the EU power system and beyond.* Link

[37] Belgian-based global materials technology and recycling group Umicore received its first loan of €125mn from the EIB to finance the construction of the greenfield production facility for cathode materials in Nysa, Poland.

Future perspectives

Now that battery production is setting up shop across Europe and that the EV market is rapidly reaching good maturity levels, several new companies are also taking position and investing in battery recycling. According to Circular Energy Storage, more than ten companies have concrete plans to start recycling lithium-ion batteries with many planning to set up large scale facilities. To name a few:

- Battery manufacturer Northvolt is aiming for 25,000t (2022)[38];
- RS Bruce Metals (UK) will set up a "full scale commercial plant";
- Duesenfeld plans to scale up significantly;
- Umicore aims for a ten fold capacity increase most probably around 2022-2023 (from 7,000 tonnes to 70,000 t per year);
- Accurec, has received funding for the planning and development of technology for a plant recycling 25,000 t annually;
- Fortum is opening a mechanical processing plant in Ikaalinen, Finland (3,000 tonnes of used batteries)[39].

It is also possible that Asian battery producers that are established in Europe could start offering their own recycling solutions, something that Samsung SDI already has done as they are part owners of Sungeel which operates pre-processing close to Samsung's own European factory in Hungary. This indicates that there could be significant competition for battery recycling on the European market which would contribute to producing price-competitive battery recycled material by driving economies of scale, increasing the utilisation of the recycling facilities and the efficiency of the processes.

According to Circular Economy Storage, the Chinese recycling capacity was at 707,000t per year in 2020, or 23 times more than Europe's recycling capacity. China's largest player, Brunp, a subsidiary of battery manufacturer CATL, has a capacity of 120,000t, or 17 times more than the European largest recycler Umicore.

3.2.3 Primary material supply

As shown previously, maximising recycling is key to minimising the impact of batteries in order to have as much secondary material as possible feeding into the system via a closed loop. However, on its own it will not be enough to meet the growing raw material needs. The remaining of the raw material demand will have to come from primary supply, while keeping its impact on the planet as low

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[38] Northvolt and the Norwegian aluminium producer Norsk Hydro announce the formation of a joint venture to enable the recycling of battery materials and aluminium for EVs.

[39] Electrive, 27 January 2021, *Fortum expands recycling business in Finland*. Link

as possible. Even when done under the highest environmental standards, mining has an impact on the surrounding ecosystem and environment and can have social impacts as well. In this section T&E assesses the origin of battery raw materials used in Europe and then provides an overview of European supply and reserves of key battery materials.

European dependence on foreign materials

The European Commission defines Critical Raw Materials as those are economically important and have a high supply risk[40]. Out of those used in lithium-ion batteries, the Commision has identified cobalt, lithium and natural graphite, see Table 2 below where nickel was added given the scale of the expected nickel demand (see previous section 3.1).

Raw material	**Main global producers**	**EU sourcing countries**	**EU import reliance**
Cobalt	Congo DR (59%) China (7%) Canada (5%)	Congo DR (68%) Finland (14%) French Guiana (5%)	86% *(81% including FR overseas department)*
Lithium	Chile (44%) China (39%) Argentina (13%)	Chile (78%) United States (8%) Russia (4%)	100%
Natural graphite	China (69%) India (12%) Brazil (8%)	China (47%) Brazil (12%) Norway (8%) Romania (2%)	98% *(90% including Norway)*
Nickel	Indonesia (30%), Philippines (16%), Russia (10%), New Caledonia (8%), Australia (7%), Canada (7%)	Exports: 11.8 kt vs. Imports 4.9 kt in 2019 [41] USA (32%), Australia (21%), Canada (20%), Russia (14%)	Above 50%[42]

Table 2: EU sourcing of key battery raw materials.

What this shows is that at present Europe depends almost entirely on external imports for raw materials. Some of these materials are almost exclusively supplied from a single country, notably lithium which is almost entirely sourced from Chile. It is also essential that the extraction of primary

[40] European Commission (2020), *Critical Raw Materials Resilience*. Link

[41] TrendEconomy, Annual International Trade Statistics by Country. Link

[42] Di Persio et al. (2020), *Information gap analysis for decision makers to move EU towards a Circular Economy for the lithium-ion battery value chain*. Link

materials does not come at the cost of the environment or of local communities; these recommendations are further detailed in section 6.

Overview of European production and reserves

Currently - similarly to oil - most of Europe's battery raw material comes from outside the Union. The EU has however expressed the ambition of achieving "strategic autonomy" on critical raw materials[43] by looking more into the availability of raw material within its borders. The table below shows the global and European production (excluding Russia), reserves and resources for lithium, nickel and cobalt. It is based on the United States Geological Survey[44] unless specified otherwise. Mineral reserves are mineral deposits which are legally, economically, and technically feasible to extract.

	Global			Europe		
Minerals	**Production (2018, in kt)**	**Reserves (in kt)**	**Resources (in kt)**	**Production (in kt)**	**Reserves (in kt)**	**Resources (in kt)**
Lithium	95	17,000	80,000	1.2[45]	60[46]	5,500[47]
Cobalt	148	7,000	145,000[48]	2.3[49]	19[50]	58[51]
Nickel	2,400	89,000	130,000[52]	71[53]	N.A.	25,000[54]

Table 3: Global and EU reserves and resources in Li, Co and Ni

[43] European Commission (2020), *Critical Raw Materials Resilience (Communication)*. Link
[44] U.S. Geological Survey (2020), *Mineral commodity summaries 2020: U.S. Geological Survey*. Link
[45] Portugal, 2019e
[46] Portugal
[47] Germany (2.5 million tons), Czech Republic (1.3 million), Serbia (1 million), Spain (300,000), Portugal (250,000), Austria and Finland (50,000)
[48] 25,000 (terrestrial) and 120,000 (manganese nodules and crusts on the ocean floors)
[49] All sourced from Finland (2016 data). In Finland, cobalt is currently produced in four mines, Talvivaara (see Box 9), Kylylahti, Kevitsa and Hitura, where it is a by-product of nickel or copper. See section 3 JRC (2018), *Cobalt: demand-supply balances in the transition to electric mobility*. Link
[50] Mainly in Finland, but also Sweden and Spain. *Ibid*
[51] *Ibid.* Mainly Spain and Sweden, while there are unconfirmed amounts in Cyprus, Slovakia, Austria, Czech Republic, Germany, Italy and Poland. Important resources are also be found in Turkey
[52] Up to 300,000 according to the Nickel Institute (Nickel Institute, January 2020, *Is there enough nickel? Reserves, resources and recycling.* Link)
[53] Mainly Finland, Greece and Spain but also Norway and Poland. Euromines, *Production by mineral.* Link
[54] Mainly France (New Caledonia), Finland, Greece and Sweden but also Poland, Spain and Norway. Source: Gavin M. Mudd and Simon M. Jowitt (2014), *A Detailed Assessment of Global Nickel Resource Trends and Endowments.* Link

Lithium: The EU aspires to become 'almost self-sufficient' on lithium by 2025 and targets 80% of Europe's lithium demand being supplied from European sources by 2025[55], which T&E calculates would amount to around 15 kt of lithium produced annually. Lithium production in Europe is currently concentrated in Portugal.

Cobalt: European reserves for cobalt are much lower than for lithium and nickel. According to the Joint Research Centre, resources are available in Spain and Sweden, while there are unconfirmed amounts in Cyprus, Slovakia, Austria, Czech Republic, Germany, Italy and Poland. New supply is subject to developments in nickel and copper markets as some 90% of cobalt is produced as a by-product of these minerals, which creates an additional challenge for the supply of the raw material.

Nickel: In Europe, nickel ore is mined in Finland, Greece, France (New Caledonia) and, on a smaller scale, in Albania, Macedonia, Serbia and Spain.

Europe has 7% of the world's lithium resources and 19% of the world's nickel resources but only 0.04% of the world's cobalt resources. To put this in perspective, these resources are enough to cover 13 times the lithium demand over the period 2020-2035, 0.26 times the cobalt demand and 8 of the nickel demand over the same period (when recycling is not fully scaled up). If reserves rather than resources are taken into consideration, Europe's lithium current reserves would cover 15%, and 8% for cobalt. On a global scale there are enough lithium resources to cover 200 times the EU needs for 2020-2035, 650 times for cobalt and 40 times for nickel. For global reserves, it would cover around 40 times the needs in lithium, and around 30 times for cobalt and nickel.

To put this in terms of the number of BEVs (based on a BEV produced in 2030), the current European reserves amount for the following number (for comparison there are around 280 million cars on the road in the EU).

Number of BEVs (in million)	**No recycling**	**EC recycling**	**T&E recycling**
Lithium	20	66	197
Cobalt	11	217	543
Nickel	349	6,975	17,439

Table 4: Current European reserves in number of BEVs (in millions)

55 European Commission (2020), *Critical Raw Materials Resilience*. Link

In short, thanks to secondary supply of materials from recycling, there is no structural longer-term risk for material availability as geological supply is sufficient for several billions of BEVs. Also, as the BEV fleet on the road gets older, the recycling market will also ramp up driven by both the market and the economics.

Section 6, presents examples of mining practices in Europe which can serve as a benchmark to minimise the impact of mining in Europe as well as how EU public and private players have the means to implement the highest environmental and social standards for domestic mining.

Info box: Copper

Copper (Cu) is one of the key raw materials present in batteries, representing 7%-8% of total weight of battery cells according to T&E calculations. According to United States Geological Survey[56], annual copper production is 20 million tonnes, with current global reserves at 870 million tonnes. The world's largest producers are Chile, Peru, China, the US and the DRC. In Europe, around one million tonne of copper were mined in 2016 (around 5% of global production) with the main deposits being in Finland, Poland, Portugal, Spain and Sweden[57].

Copper is a raw material with a mature recycling industry. According to the Copper Alliance[58], during the last decade, more than 30 percent of annual copper use came from recycled sources. In Europe alone, over 50% of copper comes from recycling[59].

Copper in the automotive sector

With increased adoption of EVs, copper demand will also rise significantly. Copper is an important element not only in batteries but also in electric traction motors and in charging infrastructure. International Copper Association (ICA) commissioned research which has shown that by 2029, annual global copper demand is set to increase by 2.3 million tonnes[60]. T&E calculates that copper demand for Li-ion batteries in Europe would increase to around 200 kt in 2035, which would reduce to around 150 kt of primary material demand once recycling of Li-ion batteries is taken into account.

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[56] U.S. Geological Survey (2020), *Mineral commodity summaries 2020: U.S. Geological Survey*. Link
[57] International Copper Study Group
[58] Copper Alliance, Copper Demand & Long-Term Availability. Link
[59] Copper Alliance, Europe's demand for copper is increasingly met by recycling. Link
[60] International Copper Association, 2.3 Million Tonne Energy Storage Boost for Copper. Link

4. Conventional cars and BEVs compared

4.1. Resource consumption

A fundamental difference between EVs and ICEs is that EVs emit zero emissions from their exhaust while diesel and petrol cars burn fuel in their engine emitting CO_2 and ultimately being one of the main causes of climate change. Over its lifetime, an average medium ICE car burns close to 17,000 liters of petrol or around 13,500 of diesel. The average fuel consumption of a medium-sized car driving over 225,000 km is calculated based on T&E's previous EV lifecycle assessment (LCA) work[61].

On the other hand, EVs are powered by the electricity stored chemically in the battery. The metals that make up the batteries are not affected by this process which means that at the end of its life, the battery will have a near-identical composition. In this subsection, we focus on the key metals that make up battery cells: lithium, cobalt, nickel, manganese, graphite, aluminium, copper[62]. For a medium-size EV with an average battery composition (i.e. weighted average of the battery chemistries placed on the market in 2020, see section 3.1 for more details on battery composition and chemistries) and a 60 kWh capacity, these materials account for around 160 kg. The remaining weight of the battery cell is mainly composed of the electrolyte, binder, separator and the battery casing (aluminum, between 20% and 30% of the total battery cell mass). Table 5 shows the breakdown of the composition of the 2020 average Li-ion battery as well as the main Li-ion battery chemistries (based on CES Online)[63].

Mass (kg)	Average 2020	NMC523	NMC622	NMC811	NCA+	LFP
Lithium	6	7	6	5	6	5
Cobalt	8	11	11	5	2	-
Nickel	29	28	32	39	43	-
Manganese	10	16	10	5	-	-
Graphite	52	53	50	45	44	66
Aluminium	35	35	33	30	30	44
Copper	20	20	19	18	17	26

[61] Based on average real world fuel consumption of most sold cars in the EU from Spritmonitor (produced after 2019). Diesel: 6L/100km, Gasoline: 7.5L/100km and BEV: 17.5 kWh/km. For more see Transport & Environment (2020), *How clean are electric cars*. Tool, report

[62] Lithium, cobalt, nickel, manganese are cathode materials, graphite is found in the anode and aluminum and copper are mainly found in the current collectors and cell casing/housing (some aluminum in the cathode for NCA batteries). Not included: electrolyte, binder, separator and the battery pack and module casing as well as iron and steel

[63] NCA+ is also sometimes referred to as NCA90

Table 5: Breakdown of the composition of the main Li-ion battery chemistries

Out of the 160 kg that make up the battery cells in the 2020 average battery, graphite, which makes up the anode, accounts for the largest share with 52 kg (or 32.5%). The second and third most present material in the battery cells are aluminum (current collectors and cell housing) with 35 kg (22%) and nickel in the cathode with 29 kg (or 18%). The average battery contains 8 kg of cobalt and 6 kg of lithium, or 5% and 4% of the total weight of the battery cells respectively.

One crucial difference between fuels used in conventional cars and batteries used in EVs is that the fuel is burnt once, whereas the battery materials can be reused and recovered in a circular loop to produce more batteries. Once a battery is too degraded in performance and its state of health (SoH, or ratio between the achievable maximum practical capacity and the theoretical capacity of a battery) falls below a certain threshold (typically 70%-80%), it is considered that the battery has reached the end of its life and would then either go to a second life application (e.g. stationary storage) or recycling. In practice, EV batteries will usually last as long as the vehicle with its ability to store energy affected over time and would fulfil the (lower) requirements owners of ageing cars have. All batteries will reach the recycling stage given that the newly proposed EU rules could ensure that all waste EV batteries placed on the EU market are recycled.

When taking into account the recycling of the battery cell materials and that the majority of the metal content is recovered, T&E calculates how much is 'consumed' or 'lost' during the lifetime of an EV. Under the proposed 2030 EC recycling recovery rate target, around 30 kilograms of metals would be lost (i.e. not recovered) for the 'average' battery considered: 1.8 kg of lithium, 0.4 kg of cobalt, 1.4 kg of nickel, 2.9 kg of manganese, 15.5 kg of graphite, 10.4 kg of aluminum and 1.0 kg of copper.

When putting into perspective the total amount of key resources that are consumed and which cannot be recovered, we show that the weight of petrol or diesel that is burned during the average lifetime of a vehicle is around 300-400 times more than the total quantity of battery cells metals 'lost' (Figure 1 below).

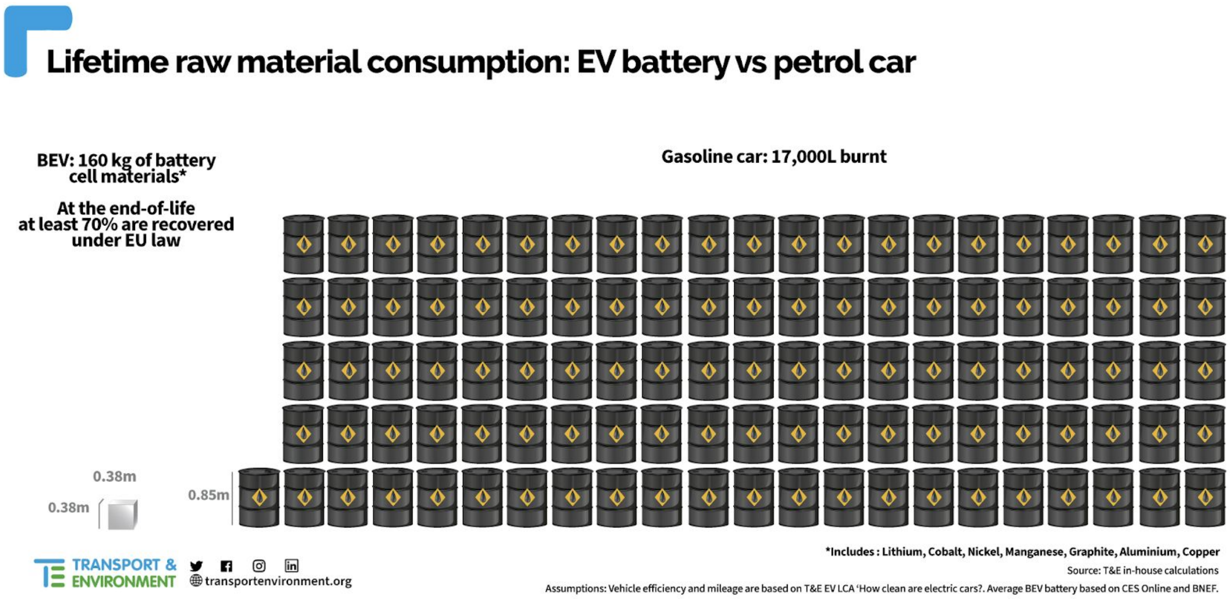


Figure 12: Lifetime consumption of resources BEVs vs. ICEs (in 2020)

The lifetime fuel consumption of the diesel and petrol cars would be equivalent to a tower of oil barrels stacked end-to-end, which is 70m high for diesel and 90m high for petrol (approximately the height of a 25 story building). If compared with a cube made up of the metals in the battery cells, the cube would be around 38 cm wide (more or less the volume of a microwave). If recycling is taken into account, the cube of metals which are 'lost' goes down to 25 cm (approximately the diameter of a football).

This visual comparison can be helpful to give an order of the scale of the amount of resources which are needed, but to fully assess the impact of the extraction of such resources, several additional factors should be taken into account: the environmental conditions of the extraction of each resource as well as the scarcity of such resources.

4.2. System energy efficiency comparison

The EU has set energy efficiency targets to reduce primary and final energy consumption as a means to 'consume less, lower energy bills, help protect the environment, mitigate climate change, improve life quality and reduce the EU's reliance on external suppliers of oil and gas'[64]. However, the EU is

[64] Targets: by 20% in 2020 (compared to 1990) and at least 32.5% (compared to projections of the expected energy use in 2030). Link

likely to miss its energy efficiency target, which unlike the EU's renewable target is not legally binding on EU Member States.[65]

Transport is the sector which accounts for the highest final energy consumption (30.8% of total) and has been increasing since 2013[66]. How efficient our transport system becomes is essential to reaching the energy efficiency targets as well as our CO_2 emissions reduction targets.

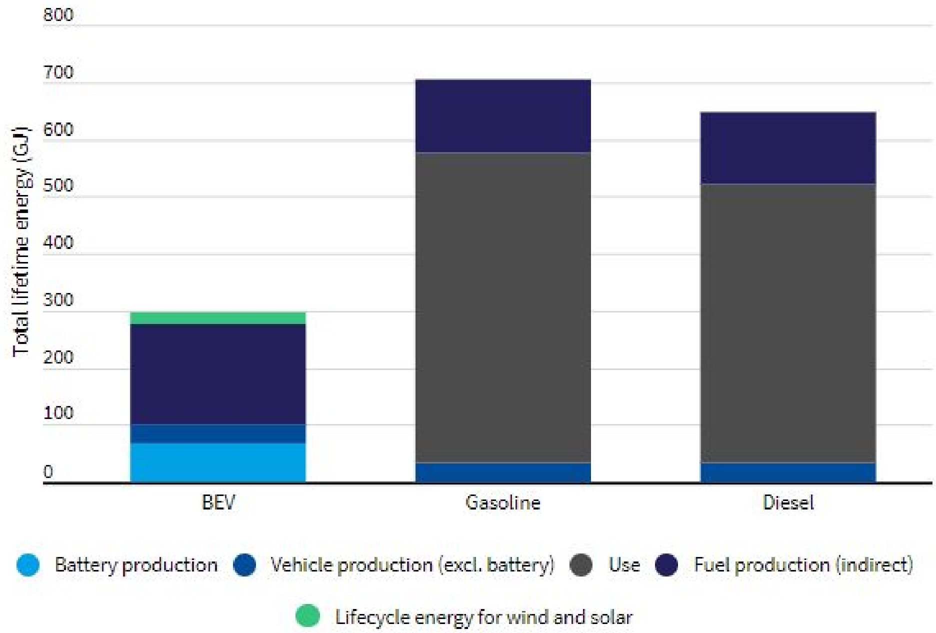
Here, we compare the lifecycle energy consumption of a **battery electric vehicle powered by renewables and a fossil-fuelled car.** This includes: energy from the production of the vehicle (including the battery), direct energy from the use phase (i.e. fuel burned in the ICE), indirect energy from the use phase (i.e. electricity to charge the BEV and upstream energy needed to extract, refine and transport the petrol or diesel fuel), and finally we have also included the lifecycle energy consumption to produce the required solar PV and wind turbines to generate the electricity the BEV then uses. **The analysis shows that over its lifetime the BEV will require 58% less energy than a petrol car**[67]: 0.37 kWh/km vs. 0.87 kWh/km (or 54% less than a diesel).

For the BEV, around 60% of that energy is from the electricity produced to recharge the car (including the various losses and efficiencies), then comes the battery production (23% of the total), the vehicle production (excluding the battery, 11%), and finally the lifecycle energy needed to produce the solar panel and wind turbines which produce the electricity (7%). On the other hand, 77% of the lifecycle energy consumption from the petrol car is directly linked to the energy content of the fuel burned in the use phase, to which another 18% accounts for the upstream energy consumption from the fuel extraction, refining, production and transportation.

[65] In 2020, the total primary energy consumption should amount to no more than 1 312 Mtoe in the EU27 and final energy consumption to no more than 959 Mtoe in 2020. In 2018, primary energy consumption in the EU was 4.9% above the efficiency target for 2020. The EU energy efficiency target for 2030 aims at a primary energy consumption of no more than 1 128 Mtoe and a final energy consumption of no more than 846 Mtoe. Euractiv, European Commission

[66] EU28 total primary energy consumption in 2017 was 1,674.9 Mt oil equivalent, which is 4% higher than its lowest point in 2014 (1,613.4 Mtoe, the lowest point reached in the 21st century). The transport sector in the EU28 amounts to 327 Mtoe in 2017. Source: EEA and Eurostat

[67] Includes upstream processes as oil production, refining, transport



Source: T&E calculations, partly based on T&E lifecycle analysis of CO2 emissions (transenv.eu/LCA)

Figure 13: Lifetime consumption of energy BEVs vs. ICEs (in MJ, in 2020)

The assumptions taken here for the petrol and diesel cars are conservative given that they do not include biofuels that are blended into petrol and diesel fuels today, which demand much more energy to produce than oil-based fuels[68]. The diesel engine is more efficient that the petrol car[69], but because of the higher energy content of diesel fuel over petrol fuel, the diesel car consumes 10% less than the petrol equivalent over its lifetime (assuming the two vehicles drive the same distance over their lifetime).

It can be noted here that the energy required to produce the solar PV and wind turbines necessary to power the BEV only accounts for 7% of the total lifecycle energy of BEVs.

[68] The energy return on energy invested (EROEI) is between 0.8 and 1.6 for ethanol and biodiesel. Using for example the mid value of 1.2, this means that you need to invest one unit of energy to get 1.2 units of energy out (i.e. only 17% of the energy will be delivered from that fuel to society). For comparison the EROIE of oil is 18, i.e. 94% of the energy from that fuel is delivered to society. Link
[69] 20% less fuel consumption per km based on our assumptions for top vehicles sold in the EU

Info box: What about PHEVs and FCEVs?[70]

The well-to-wheel efficiency of the direct electrification pathway is 77% while it is only 30% for the hydrogen pathway, which means that 2.6 times more electricity is needed to power the hydrogen car over the same distance. As a result, if we conservatively exclude the impact of the production of the fuel cell for the vehicle, the energy consumed over the lifetime of the vehicle is around 24% less than for a petrol car and 80% more than for a BEV.

With regards to PHEVs, depending on the share of kilometers which are driven on the electric powertrain (which itself is directly linked to the charging behavior) the lifecycle energy consumption would be somewhere between the consumption of the BEV and petrol car. For indicative purposes, if the PHEV has a 15 kWh battery and half of the distance travelled is done on the electric motor, then the lifecycle every consumption would be 42% higher than for BEVs and 41% lower than for gasoline. This result is optimistic for PHEVs given that today only 20% of the distance driven by company car PHEVs is electric, and 37% for private PHEVs[71].

As noted in a recent study[72] by T&E, the very large amount of renewables needed to electrify road transport is a great challenge, and can only be addressed if we focus on the most efficient options - i.e. battery electric vehicles. The report shows that for cars, vans and lighter trucks (< 16 t) a small share of hydrogen and synthetic hydrocarbon use in light-duty vehicles makes a big difference. Even a relatively small share of light-duty vehicles (10-20%) using hydrogen or synthetic hydrocarbons (e-diesel or e-gasoline) in 2030 will significantly increase the electricity needs for road transport. By 2030, relying on just 10% fuel cell vehicles will increase the renewable electricity demand by 12% (equivalent to 1.7 extra 2 GW offshore wind farms). Relying - in addition - on 10% synthetic hydrocarbons use will increase the renewables demand by 31% (equivalent to 6 extra 2 GW offshore wind farms).

4.3 CO_2 emissions: BEV emit almost 3 times less

In 2020, T&E produced a comprehensive lifecycle analysis of CO_2 emissions from electric cars and compared it with diesel and petrol cars for 2020 and 2030 and for different car sizes. The online tool

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[70] BEV cars require 0.85 MJ/km on average or 37% of fossil fuel cars, FCEV cars need to convert hydrogen into electricity which results in a lower efficiency (1.48 MJ/km or 64% of fossil fuel cars) and PHEV cars have an average energy efficiency closer to fossil fuel cars (1.81 MJ/km).
[71] ICCT (2020), *Fact sheet: Real-world usage of plug-in hybrid electric vehicles.* Link
[72] Transport & Environment (2020), *Electrofuels? Yes, we can … if we're efficient*. Link

(transenv.eu/lca), published alongside the paper[73], is based on the latest evidence that shows that an average EU electric car is already **close to three times better than an equivalent conventional car in 2020**. Crucially, electric cars will become considerably cleaner in the next few years as the EU economy decarbonises, with average EVs more than four times cleaner than conventional equivalents in 2030.

Electric cars outperform diesels and petrols in all scenarios, even on carbon intensive grids such as Poland, where they are about 30% better than conventional cars. In the best case scenario (an EV running on clean electricity with a battery produced with clean electricity), EVs are already about five times cleaner than conventional equivalents. The evidence shows that electric cars - powered with the average European electricity - repay their "carbon debt" from the production of the battery after just over a year and save more than 30 tCO_2 over their lifetime compared to their conventional equivalent. Electric vehicles that do high mileage (e.g. shared vehicles, taxis or ride-hailing services) save up to 85 tCO_2 over their lifetime (compared to diesel).

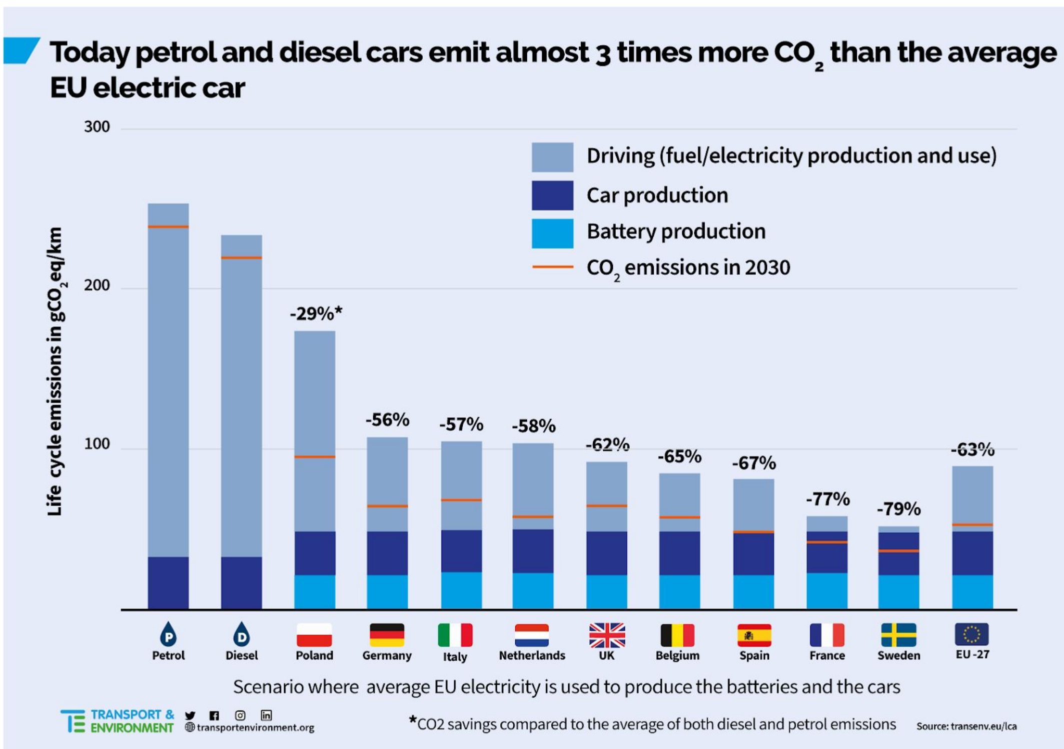

Figure 14: Lifecycle analysis for CO_2 emissions of electric cars

[73] Transport & Environment (2020), *How clean are electric cars? T&E's analysis of electric car lifecycle CO_2 emissions.* Link

T&E will update its LCA analysis in the first half of 2021 and add PHEVs to this comparison in the light of the growing evidence produced in 2020. Vehicle energy consumption and electricity carbon intensity data will also be updated.

4.4 Costs: BEVs are significantly cheaper

In this section we cover the cost aspects of the electric cars in comparison with the ICE car in three parts: first an assessment of the drop in battery costs, second a cost comparison between BEV and ICE from the user perspective and third we compare capital investments in BEV versus ICEs.

BEV average battery cell prices reached $100/kWh in 2020

Batteries are an evolving technology, and as such they are subject to great cost reduction from economies of scale and technological improvements. As these kick-in, capital-investment costs will fall dramatically over time while the marginal cost of using the batteries is near zero.

Battery prices have been falling at a staggering speed this last decade. Lithium-ion battery pack prices, which were above $1,100 per kilowatt-hour in 2010, have fallen 89% in real terms to $137/kWh in 2020 (€112/kWh).[74] This is a 13% drop compared to the previous year (and same reduction as the year prior to that). However this is a global volume-weighted average covering batteries from all different markets and across all sectors and applications (electric LDVs, electric HDVs, stationary storage etc). In 2020, BEV battery prices were $126/kWh on average (€103/kWh) and dropped faster than the average (15% vs 13%)[75]. At the cell level, BEV batteries have reached $100/kWh on average, this indicates that on average, the battery pack portion of the total price accounts for 21% of a BEV. For the first time, battery pack prices of less than $100/kWh have been reported in 2020. BNEF forecasts that by 2023, average pack prices will be close to $100/kWh thanks mainly to increasing in order size and new pack designs which cause manufacturing costs to fall.

Beyond research organisations like BNEF, the battery and auto industry sector are also claiming similar trends. According to a 2019 report from The New York Times, a Volkswagen executive said the automaker pays less than $100/kWh for its batteries, but it is likely they are talking about battery cell cost or module not battery pack cost[76]. Tesla CEO Elon Musk suggested in 2018 that Tesla was close to

[74] BloombergNEF (2020), *Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at* $137/kWh. Link
[75] Frith, James (2020, December, 17) Tweet
[76] Ewing, Jack (Sept. 8, 2019), *Volkswagen Hopes Fresh Logo Signals an Emission-Free Future. Link*

crossing the $100/kWh threshold for its batteries, but the electric-car maker has not since confirmed if it has reached that point yet[77].

User perspective: BEVs are significantly cheaper over the life of the vehicle

Over the average lifetime of 225,000km, a medium-sized vehicle incurs a total energy cost of around €8,400 for BEVs and around 2.5 times higher - €21,000 - for a petrol car[78] (includes the cost of the electricity and the cost of the average petrol fuel in the second half of 2020). Even when taking into account the additional battery costs (around €6,200 in 2020 prices for a 60 kWh battery) and conservatively assuming that the BEV without the battery costs the same as the ICE car, and that other operational costs are on par (e.g. maintenance, insurance etc) T&E show that over the lifetime, the BEV costs €7,000 less, see Figure X.

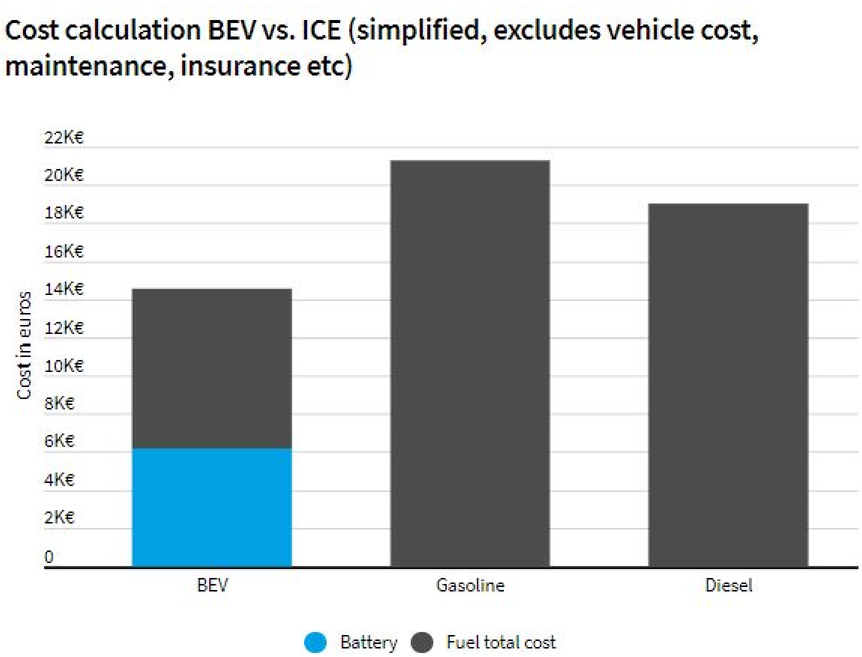

Figure 15: Lifetime cost comparison for energy and battery, BEVs vs. ICEs

[77] Mark Matousek, Mark (2019, September 10), *Volkswagen has reportedly reached a big milestone in battery costs that would heat up its competition with Tesla.* Link

[78] Average EU27 household electricity price: 0.2126 €/kWh (Eurostat). Average EU27 fuel price: 1.262 €/L for gasoline and 1.124 €/L for diesel (including all taxes). Average fuel prices during the second half of 2020 are used in order to exclude crude oil price fluctuations from the first half of 2020 from the scope. Source: Weekly Oil Bulletin

The much lower costs for BEVs means that on a system perspective, this would create enormous costs saving for Europeans as oil imports would be greatly reduced. For more on the system cost and dependency, see section 5.

On the basis of a total-cost of ownership calculation, BEVs are today as expensive as diesel and hybrid equivalents for a car running 15,000 km and an ownership period of 5 years, see Figure X in Annex[79].

BEVs powered with renewables produce six to seven times more useful energy for a given investment

The last cost component analysis is a comparison from a capital investment point of view, taken from a report from BNP Paribas from 2019[80]. The report investigates how much useful energy at the wheels do we get for a given capital outlay on oil and renewables by introducing the concept of the Energy Return on Capital Invested (EROCI). The analysis indicates that for the same capital outlay in 2019, new wind and solar-energy projects together with BEVs will produce six to seven times more useful energy at the wheels (or transport work) than will oil for gasoline-powered cars (at $60/barrel). According to the report, the long-term break-even oil price for ICEs to remain competitive as a source of mobility is between $10 and $20 per barrel[81] where the averaged in 2019 was $64 per barrel and $41 in 2020[82].

The report points out that oil has a massive scale advantage, but this is time limited given the economic and environmental benefits of the tandem EVs plus renewables. Of course, there remain big infrastructure challenges to be overcome – and paid for – if the potential of renewables with EVs is to be fulfilled over the next two decades. But as the net-energy yield over the full lifecycle of renewables versus oil will only continue to improve over the next decade, the competitive advantage is set to shift decisively in favour of EVs over oil-powered cars in the next five years. The report concludes that EVs powered with renewables could readily replace up to 40% of global oil demand if it had the necessary scale, and that diesel and gasoline are economically unsustainable as light duty vehicle fuels.

While EVs are more beneficial than ICEs when comparing material requirements, energy needs and CO_2 emissions, the years to come will see a sharp increase in demand for batteries and resources to produce them. Next chapters dive deeper into the battery resource issues around demand and supply and consider wider implications for Europe.

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[79] For more details on T&E's TCO calculations, see T&E (2020), *Why Uber should go electric.* Link

[80] Mark Lewis (2019), Wells, wires and wheels - EROCI and the tough road ahead for oil. Link. Mark Lewis is Global Head of Sustainability Research at BNP Paribas Asset Management

[81] Long-term break-even price: $9-10/barrel for gasoline and $17-19/ barrel for diesel

[82] The price of Brent crude oil, the international benchmark. EIA expects Brent crude oil prices to average $53/b in both 2021 and 2022. EIA (2021), *Short term energy outlook.* Link

5. Dependency on resources: batteries vs. oil

5.1 Oil dependency in the EU

Crude oil and petroleum products account for close to half of energy available for final consumption in the EU[83] and the transport sector accounts for more than two thirds of the block's final demand for oil and petroleum products (73% for road transport). The heavy reliance on oil exposes the EU to geopolitical risk because of its high dependence on imports and impacts the EU's economy significantly (for more on Europe's oil dependency, see infobox below). In the EU 2030 Climate Target plan impact assessment, the European Commission calculated that oil will still account for 85%-89% of total energy demand from transport (from 94% currently) underlining the need to reduce more rapidly our reliance on oil.[84]

Historical trends in EU oil dependency[85]

Although domestic energy demand has fallen in recent years, crude oil extraction in the EU-27 has fallen at a faster rate. Brexit has exacerbated this trend, since the UK accounted for 70% of EU28 crude extraction in 2018, leading to an increased EU dependency on oil imports. As of 2018, the EU-27 rely on imports for 96% of its crude oil supply. For the EU28, the figure was 88%. In 2018, the EU spent €211 bn overall in crude oil imports. As shown in section 3.2.3, the EU's dependency on imports for battery materials are also high (above 50% for nickel, 86% for cobalt and 100% for lithium).

Since 2015, there has been an increase in the volume of oil imported, as the lower oil price has driven a reduction in domestic production and an increase in demand. In 2018, crude oil imports (in volume terms) were 8% higher than in 2014, and in 2017 they reached their highest level since 2008.

Exposure to security of supply risk

A high proportion of EU oil imports are from geopolitically unstable regions that have seen increases in terrorism, internal and border conflicts, or even wars. As a result, consumers and industries in the EU face an increased risk of oil supply interruptions and shortages. It is estimated that over 80% of crude oil imports and 95% of refined oil imports to the EU are from non-European companies. Since much of the economic value added in the oil supply chain is based outside the EU, the oil exporting regions benefit from the jobs and investments.

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[83] Or 37% of the final consumption in energy use (Eurostat Balance Sheets)

[84] Oil demand for EU transport: from around 320 Mtoe today to 293-272 Mtoe.

[85] Cambridge Econometrics (2020), *Oil Dependency in the EU*. Link

No tracking or transparency

The oil supply chain suffers from a complete lack of tracking and transparency, especially on the type of crude oil used in the petroleum products that Europe imports. Because of this it is very difficult to have a clear idea of what type of oil enters Europe overall, where exactly it has been extracted and how. This information would be particularly important to know for the dirtiest types of oil like tar sands oil (Commission study assumes that on average tar sands are 23% worse than conventional crude oil)[86].

5.2 Comparison with batteries

A mass comparison

Measured by mass, the order of magnitude of the dependency on oil is several orders of magnitudes higher than for metals, even when looking well into the future. Oil consumption for passenger cars in the EU27 + UK is estimated around 167 Mtoe[87] which is equivalent to 1.3 billion barrels of oil. If these barrels of oil were placed on top of each other, the tower would be more than one million kilometers in height, or close to three times the distance between the Earth and the Moon. In 2030, this demand would reduce to around 150 Mtoe and 106 Mtoe in 2035, or 145 Mt of petrol and diesel in 2030 and around 100 Mt in 2030.

On the other hand, the total primary cell raw material demand for batteries would account for around 1.1 Mt in 2030 and 1.3 Mt in 2035 (excluding electrolyte, binder, separator and the battery pack and module casing). Together nickel, cobalt and lithium would account for 0.3 Mt in 2030 and 0.4 Mt in 2035 (or less than 30%). If all these battery cell materials were put together, it would amount to a single cube 71 meters large in 2030 (75 meters large in 2035).

In short, the dependency on oil in 2030 will be around 130 times higher (in mass) than for battery metals in 2030 and this factor could decrease to around 80 in 2035. If we limit it to nickel, lithium and cobalt only, the oil needs (in mass) are then 460 times higher in 2030 and 270 times higher in 2035.

The level of battery cell material demand for EVs reached in 2035 is likely to be the upper limit of what would be the maximum battery cell demand for vehicles in the EU. This is justified by three main

[86] Transport & Environment (2013), *Tar sands and the Fuel Quality Directive - what is it all about?.* Link

[87] Energy demand from passenger cars in 2010 at 173,396 ktoe in 2010 according to Ricardo (2016), *Exploration of EU road vehicle fuel consumption and disaggregation, Final Report for the European Commission, DG Climate Action* Link. Assumed to increase by 3% from 2010 to 2018 (i.e. same evolution as the whole of road transport total energy consumption: from 298.6 Mtoe in 2010 to 306.7 Mtoe in 2018). Oil share in road transport energy demand at 94%. Source: Eurostat Energy Balance Sheet, road transport (FC_TRA_ROAD_E)

reasons: 1) the T&E scenario considered here models a full phase-out of ICEs by 2035, 2) improvement of battery energy density will continue to improve beyond 2035 (and is likely underestimated in this work), and 3) ramp-up of recycling thanks to higher number of EVs reaching end-of-life as well as expected improvements in recovery rates. Theoretically, in a steady state situation (all cars on the road are BEVs, with each end-of-life batteries providing recycled material for a new BEV), then -based on the 2035 battery assumption used here- the total annual demand for battery cell materials would be 0.3 Mt with only around 15 kt for lithium, nickel and cobalt combined.

Economic comparison

Even though per mass, metals for batteries are more expensive than oil, at current prices the EU would still spend significantly less on key battery metals in 2030 and 2035 compared to oil.

Based on 2019 metal prices, the EU would need around 4 billion euros worth of lithium, cobalt, nickel in 2030. In 2035, this would increase to 4.5 billion euros. If recycling is not taken into account, the need for virgin raw materials would increase to 6 billion euros in 2035. A large share of these materials would have to be imported and nickel would account for around 80% of the total value.

Current metal and oil prices are relatively low, but trends are very uncertain as it was illustrated by the important price volatility for some of these commodities in the recent years. For example, crude oil prices reached their 2020 lowest price at $20/barrel in April and their highest point at $69/barrel in January. Cobalt, which has surged $94/kg in 2018 has varied between $28/kg and $34/kg in the year 2020.

Short term price volatility can be mitigated if new supply of battery materials (mining and refining) ramps up quickly and matches the increase in material demand in the coming years. Otherwise, short-term increase in prices could occur. In the longer term, thanks to recycling and a catch up of the supply, there is less risk of supply bottlenecks or price increases. Furthermore, following the COVID-19 crisis and wider over-capacity in the car industry, the overall car market is likely to be smaller compared to what was expected in previous forecasts (the contraction of the passenger car market in the EU was of -23.7% in 2020), which could reduce the pressure on the demand for raw materials.

On the other hand, T&E calculates that in 2030, oil demand for passenger cars would still account for close to 60 billion euros, or approximately fifteen times more than the value for key battery metals (lithium nickel and cobalt, based on the 2019 average price for a barrel, or 64 US dollars). Even in 2035, the EU will still spend close to ten times more on oil imports than on key battery cell materials. As most oil is imported, demand for oil results in large amounts of money leaving the European economy.

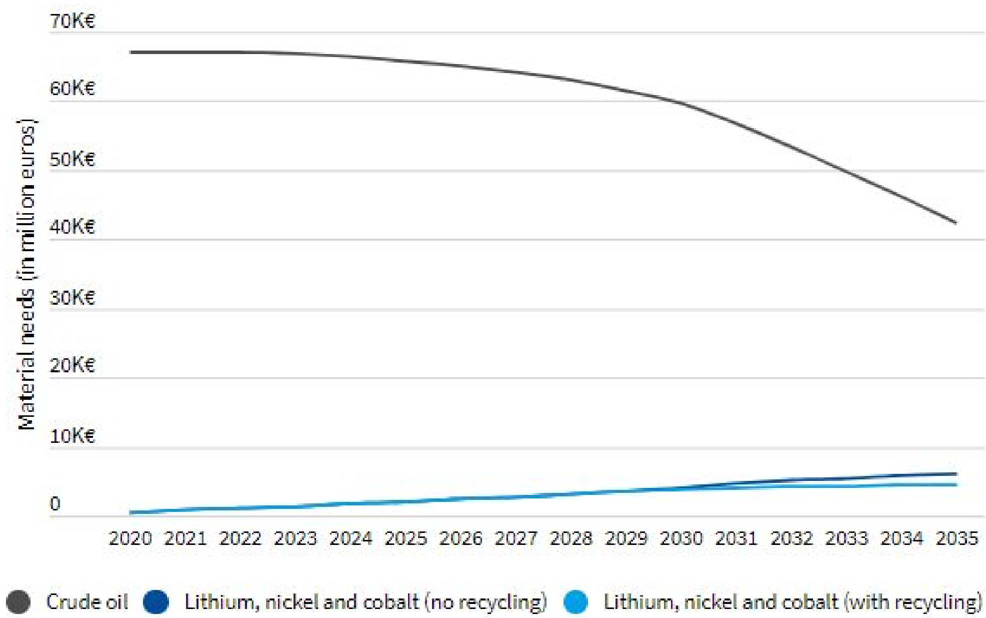

Figure 16: Cost of material needs for battery key cathode metals vs. oil

6. Policy recommendations

The following section outlines how Europe can shift to a sustainable zero-emission mobility system and the path that the EU should take to create the most sustainable battery value chain, from sourcing all the way to recycling by meeting the highest environmental and social standards.

6.1 Sustainable zero emission mobility system

6.1.1. Car CO_2 regulation: Accelerate the shift to zero emission cars

The analysis in this paper shows that batteries are far better from a system point of view of resources and energy consumption than fossil fuels. Together with climate change, this is a key reason why Europe should shift away from combustion cars, accelerating its transition to battery electric vehicles. For this reason, it is crucial that Europe:

- Accelerates the EV transition: increase the car CO_2 regulation 2025 review target to at least -25% (below 2021 levels) as well as raising the 2030 target to -65%, and sets an intermediate 2027 target to ensure continuous investment and CO_2 reduction.
- Sets a long-term zero emission goal: builds on the current momentum in many countries and cities by setting an EU-wide phase-out date for the sale of new cars with internal combustion engines, no later than 2035, flanked by a European automotive transition fund.
- Resists pressure from the oil and gas industry to weaken the regulation via fuel credits for alternative fuels, and ensure engines and fuels continue to be governed in separate tailored laws in the EU.

The growing EV market masks many regulatory flaws and failures to cut emissions, such as the increasing CO_2 emissions from new cars prior to 2020 and the push by some carmakers towards suboptimal plug-in hybrid technology. The biggest risk is that the EV momentum will stagnate between 2022-2029 unless the current standards are strengthened.

6.1.2. Less (cars) is more

A technological shift from ICEs to BEVs has the potential to generate very important climate mitigation benefits. However, this still leaves the EU with some environmental and social challenges, namely the global increase in extraction of battery raw materials (along with the reliance on imports) and dependency on an inefficient private car based system. The global extraction of raw material has for centuries been associated with environmental and social concerns and is not singular to the metals needed for battery technology.

Technology should be complemented by policy choices, both at supranational and at local level, to make our mobility system sustainable at all levels. Policy choices have a role to play in shaping the future of transportation especially in environments such as cities with the overarching objective being reducing the demand for cars through a systemic approach to mobility.

There are many solutions that can successfully contribute to reducing the number of vehicles on the road[88]. Whilst car and ride sharing plays an important role, cities must first adopt a holistic approach to their mobility systems, with smart investments in existing public transport and infrastructure, as well investing in active and micro-mobility (i.e. bike and e-scooter sharing) ultimately reducing the overall number of private vehicles in cities. Privately owned diesel and petrol cars should be banned from EU city centres by 2025.

There are no silver bullets but lowering the energy and material demand in the transport sector by promoting public transport, shared vehicle use, modal shift, logistics efficiency and reducing air travel can help to reduce the scale of the challenge.

6.2 EU sustainable battery regulation

On December 10th 2020, the European Commission presented the first ever sustainable battery law, aiming at ensuring that "*only the greenest, best performing and safest batteries make it onto the EU market*". In this section T&E aims at analyzing key aspects of the proposal, with relative recommendations on how to strengthen it, ultimately aiming at effectively having the greenest batteries on the European market.

6.2.1 Responsible supply chains

In the previous sections T&E explored how the raw materials needed to power the mobility transition are sourced across the globe. The speed at which the shift to electromobility is happening will, with no doubt, put pressure on supply chains, risking to ultimately also put pressure on the environment and on local communities. For this reason, it is crucial that strong due diligence standards are implemented across the entirety of battery supply chains from raw material sourcing to manufacturing. It needs to be stressed that similar requirements should also be implemented for all

[88] Transport & Environment (2019). *Less (cars) is more: how to go from new to sustainable mobility*. Link

raw materials extraction whether for EVs or not - as part of the upcoming legislation on mandatory due diligence in the supply chain the European Commission is due to propose in the first half of 2021[89].

The European Commission in its proposed regulation has asked for the implementation of mandatory due diligence standards based on the OECD's Due Diligence Guidance for Responsible Supply Chains of lithium, nickel, cobalt, natural graphite and of chemical compounds necessary for the manufacturing of the active materials of batteries. This will apply to the global supply chains of batteries placed on the EU market, and so will have a global impact.

With mining often being the most sensitive part of the supply chain, through making said guidelines mandatory for companies placing batteries on the EU market, policy makers would be able to enforce the establishment of strong management systems. Those in turn would create a system of transparency, information collection, and records of supply chain due diligence processes, findings and resulting decisions with relevant information related to mine of origin, production, transport, trade, export and the identities of any suppliers of minerals. Regular auditing of the supply chain would allow for early identification of potential red flags such as human rights abuses or money laundering for example, providing businesses the opportunity to act on them prematurely.

Companies that place batteries on the market are furthermore asked to apply due diligence procedures to the whole supply chain: that includes mines, but also refineries and assembly plants.

6.2.1.1 What the EU should improve

Copper

The Commission draft proposal, as aforementioned, asks for the supply chain of key battery raw materials to comply with due diligence standards. However, one is notably absent: copper. With it being a key component of batteries and mined alongside cobalt[90], T&E fears that should the raw material not be included in the list, we may see a fragmented approach to due diligence especially in more sensitive parts of the globe.

Furthermore, copper is also strategic from a recycling point of view, therefore it is important that its supply chain is also as responsible and "clean" as possible, especially considering the consequences that unregulated copper extraction can have[91].

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89 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12548-Sustainable-corporate-governance

90 Cobalt can be a by-product of copper mining, as it is in the DRC copper belt. Link

91 https://old.danwatch.dk/undersogelseskapitel/impacts-of-copper-mining-on-people-and-nature/

International instruments

Whilst the Commission proposal recognises[92] the impact that mining and other battery-related processes such as recycling have on the environment, on workers and on communities, it only acknowledges a limited number[93] of internationally recognised instruments that are designed to protect the most vulnerable. For example, the inclusion of ILO Convention 169 on the right of Indigenous Peoples to Free, Prior, and Informed consent - although already included in other instruments listed in Annex X including the Tripartite Declaration of Principles concerning MNEs and Social Policy - should be clearly stated given its importance to the rights of mining-affected communities. Improvements should also be made to strengthen environmental protection. With one in every three allegations[94] related to raw material extraction linked to water (pollution or access to), Annex X should address this issue by including adequate steps such as IRMA's Water Management requirements, listed under the standard's environmental responsibility practices[95].

In addition to above-mentioned instruments, specifically at mine-level, T&E believes stronger environmental protection for global mining practices is required. The Initiative for Responsible Mining Assurance (IRMA)'s Principle 4: Environmental Responsibility, sets out a comprehensive overview of what responsible mining - and beyond - should look like at the industrial-scale, providing a list that can be used as a benchmark from waste and materials management all the way to biodiversity protection.

Artisanal and Small scale Mining

Furthermore, the Commission does not individually address Artisanal and Small-Scale Mining (ASM), a sector that represents 20%[96] of cobalt extraction in the Democratic Republic of Congo (DRC), for instance. T&E believes a separate strategy on ASM is needed, through involving miners and ensuring local communities also benefit through trade and development policies aimed at formalising the sector, establishing cooperatives and improving health and safety conditions. Through its EU-Africa Partnership and EU development policy for instance, Europe should provide formal support to turn current pilots into pan-industry practice and fund large-scale formalisation activities that span across mines and many years, etc. Europe should also include clauses in all its trade agreements on

[92] https://ec.europa.eu/environment/waste/batteries/pdf/Annexes-Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf

[93] This refers to the list of international instruments listed in Annex X point 3 of the proposed regulation on batteries.

[94] Business & Human Rights Resource Centre (2021), Transition Minerals Tracker. Link

[95] https://responsiblemining.net/wp-content/uploads/2018/08/Chapter_4.2_Water_Management.pdf

[96] Amnesty International (2016). *Is my phone powered by child labour?*. Link

compliance with the OECD guidelines for the import of raw materials. In Congo specifically, but not exclusively, the EU could provide support to develop domestic refining capacity so that they can export the processed higher value material to Europe directly, instead of going via China. This will not only aid development and jobs, but will also shorten supply chains and thus slash transport emissions associated with battery production.

Voluntary schemes and independent auditing

T&E wishes to see regular third-party auditing of recognised voluntary schemes by EU institutions to ensure continued enforcement throughout. This independent auditing should also be applied to companies that are participating in existing - albeit recognised - voluntary supply chain certification schemes as such schemes may not automatically meet compliance criteria. In the case of the biofuels industry for instance, it was found that the standards presented by the voluntary schemes as a basis for their recognition were not always applied in practice and that they were not ultimately verified by the authorities[97].

Furthermore, policy makers should mandate on all companies adhering to voluntary schemes an annual due diligence public report including a supply chain risk assessment as it is required by the Due Diligence Guidance for Responsible Supply Chains. This should be specifically mandated as some voluntary schemes do not always ask of their members such a requirement.

It should be noted that no similar requirements for due diligence and traceability exist for oil supply as details on how oil has been extracted and whether environmental and social safeguards have been respected do not need to be provided and verified by a third party. Oil should as well be covered as soon as possible by similar requirements.

6.2.2 Low carbon batteries

The shift towards clean manufacturing - and clean supply chains - are central in ensuring that the batteries placed on the market have the lowest carbon footprint possible. In order to achieve this, it follows that where battery (and battery cell) production is situated and the carbon-content of the electricity used are crucial to determining how green the battery actually is.

The European Commission's proposed regulation takes an important step to ensuring battery production is incentivised where there is availability of clean and renewable electricity. The proposal in fact requires manufacturers to disclose not only plant-specific emissions and energy use data that is

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[97] Transport & Environment (September 2, 2016), *Sustainable' biofuels certification challenged by EU auditors*. Link

specific to manufacturing process, factory, and location, but also information about the wider supply chain and lifecycle including raw materials acquisition and processing, distribution and end of life processes.

With the detail of a battery's carbon footprint declaration to be decided in the coming years, it is crucial that the regulation:

- Does not allow battery manufacturers to use Guarantees of Origin (GOs) to prove use of renewable energy as they provide only a fictional link between the generation and use of the energy. Furthermore, there is no direct link between the market value of GOs and the revenue required to make new investments in renewable power attractive. Instead, it should require manufacturers to enter into Power Purchase Agreements, which help finance and deploy additional renewables on the grid, or to use direct connection to an off-grid renewable energy plant;
- Does not provide the possibility for companies to offset their emissions;
- Sets ambitious and future proof maximum carbon footprint thresholds that take account of industry-wide best practice;
- Where a company does not provide sufficient or accurate data, default values to be used as emission factors should be established on the conservative end of the spectrum - as a minimum the carbon intensity of the electricity of the country where electrodes, electrolytes and cells were produced should be used. Companies should be allowed to use lower emission factors only where they can reliably prove that their individual processes or energy sources are better.

Ambitious carbon footprint rules can ultimately represent a double win both for climate and for European manufacturing by restricting imports of higher carbon batteries. It is also an opportunity for the European battery industry to become the global leader in the production of sustainable low-carbon batteries.

Low-carbon mining

The EU's proposed law rightly wants to address carbon footprint beyond battery production, focusing on the mining sector. While the EU should strive to reduce the need for new mining as much as possible, improving mining processes can in fact be part of the solution, through ambitious emissions targets reduction and through the adoption of innovative technologies that can ultimately reduce the impact of extracting raw materials on the environment from a carbon footprint point of view. There are several examples of responsible mining practice in Europe which could serve as inspiration for any new mining activities, as targeted by the EU under its critical raw material strategy.

For example, according to a research paper published by the European Federation of Geologists, one of the ten active mines in Finland deploys "a unique and energy-efficient way to extract metals with about 40% less greenhouse gas emissions and 20% less energy consumption than the average for nickel production."[98]. Or, another example is the first zero carbon lithium extraction project in Germany[99] - Vulcan's "Zero Carbon Lithium" - which uses a closed-loop geothermal extraction system. This could be replicated around the Union on similar lithium, cobalt or nickel domestic sources of supply. Ultimately, domestic mining fully empowers EU public and private players with the means to fully minimise the impact of mining and respect the highest environmental and social standards.

6.2.3 Recycling

As outlined previously in the infobox in section 3.2.1, the European Commission has proposed new specific recycling targets for lithium-ion batteries. The proposal asks for specific rates to be recovered for cobalt, nickel, lithium and copper as well as requiring new batteries to have, for the first time, a minimum recycled content as of 2030.

If Europe is to become a leading player in the battery value chain, recycling is an important piece of the puzzle. It must be prioritised ahead of new mining as it will be crucial to offset supply risks, price fluctuations and environmental and social concerns. At present, however, Europe has very limited recycling capacity[100], with many batteries being sent to China.

Recycling is central to Europe's battery success story and it can only happen with the appropriate regulatory ambition, accompanied by smart business investments.

The currently proposed targets mandate a recycling efficiency (ratio between the weight of recycling input and recycling output)[101] for lithium-ion batteries of 65% by 2025, and of 70% by 2030 based on weight. Moreover, the proposal asks for specific material recovery rates for cobalt, nickel, lithium and copper, which T&E recommends to increase further in order to reduce the imports from virgin raw materials.

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[98] Dehaine, Q. et al., (2020), *Battery minerals from Finland: Improving the supply chain for the EU battery industry using a geometallurgical approach*. Link
[99] InnoEnergy (21 July, 2020), *World's first zero carbon lithium extraction project to start in Germany*. Link
[100] Transport & Environment (2019), *Batteries on wheels: the role of battery electric cars in the EU power system and beyond.* Link
[101] Recycling efficiency is the ratio between the weight of recycling input and recycling output.

	Commission proposed targets		T&E targets	
	Co, Ni, Cu	Li	Co, Ni, Cu	Li
2025	90%	35%	95%	70%
2030	95%	70%	98%	90%

Table 6: Comparison of recycling targets

The current proposed targets are below what industrial processes can achieve today, in particular for lithium, as shown in section 3.2.1. More ambitious objectives can ultimately place the EU as a technology leader.

It is ultimately key to step up research and development efforts, deploying results at large scale in recycling, substitution and material efficiency, thereby reducing the need for primary raw materials, and ensuring security of supply also bringing substantial environmental benefits.

6.3 Battery industrial policy

For batteries to become Europe's success story, strong industrial policy is also needed with the objective of establishing a resilient, innovative and clean leading European industry.

Securing supply

In this paper, T&E has calculated the expected production level of battery cells based on industry announcements. However, the industry announcements about the level of investment, the anticipated timeline, and expected production volumes for new and expanded mining and refining are generally less publicly available, as well as the industry announcements for supply of raw materials. Given the scale of the increase of raw materials needed to produce EVs in Europe, there is also an important need for investment to flow upstream. This is necessary to ensure that the pace and scale of raw material mining and chemical refining parallels that of battery manufacturing.

Following the first weeks after the COVID-19 pandemic, many companies have delayed or slashed their budgets for planned investments, according to the IEA[102], with early data suggesting that new project approvals are slowing and that annual exploration budgets are likely to fall by 29% compared with 2019, which could have longer-term implications for supply[103]. These spending cuts are disproportionately affecting new mines or new entrants to the market, limiting the scope for buyers to

[102] IEA, May 2020, *Clean energy progress after the Covid-19 crisis will need reliable supplies of critical minerals.* Link

[103] S&P Global (2020), *Pandemic expected to push exploration budgets 29% lower in 2020*. Link

diversify sources of supply or localise supply chains and coming at a time of rapidly acceleration of the demand for battery raw materials with the surge of electric car sales.

On top of minimizing the environmental impact of every step of the battery value chain, EU public and private actors should also focus on making the overall industry more resilient and less dependent in a more unstable post-COVID-19 world. OEMs will need to take a stronger foot in the battery supply chains in order to reach the rapid growth and have strategic security for the supply over the short and medium term. Moving more upstream in the value chain and increasing vertical integration - a practice which is widely adopted in China and South Korea - is key for the industry to create more resilience to supply variations and price volatility, which will become increasingly relevant and necessary in the future. This will also be helpful and even necessary for OEMs to rapidly clean up their supply chains by increasing their control and imposing higher environmental and social standards[104]. Redirecting the current focus on global mining with Asian refining of cathode materials to build a European supply chain would further reduce the shipping of materials as well as political risk, and create more jobs in the EU.

Finally, these considerations for vertical integration are also very relevant for the most downstream part - the recycling of batteries - as it would allow the industry to create synergies between the upstream and downstream parts and strive for battery circular economy.

European Battery Innovation and advanced batteries

Following the success of the European Battery Alliance, the Commission has approved a second Important Project of Common European Interest ("IPCEI") to support research and innovation in the battery value chain, called "European Battery Innovation"[105]. The twelve Member States will provide up to €2.9 billion in funding in the coming years. The public funding is expected to unlock an additional €9 billion in private investments. This project covers 'raw and advanced materials', battery cells and systems and 'recycling and sustainability' with a strong focus on the next generation of batteries, where the EU has the opportunity to become a leader.

Regarding future battery technologies developments, the head start of other global regions is very small compared to the EU. This could offer Europe the potential to become a hub for advanced

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[104] Given that the EU due diligence requirements are likely to be applicable 12 months after the regulation has entered into force, if OEMs rely on imported batteries, the due diligence requirements fall upon them and could pose some challenges to OEMs if foreign battery suppliers are not able to fulfill the requirements in time. In this situation, vertical integration where OEMs and/or battery producers control parts of the upstream battery production could also help as they can provide the relevant information more easily.

[105] European Commission, 26 January 2021, *State aid: Commission approves €2.9 billion public support by twelve Member States for a second pan-European research and innovation project along the entire battery value chain.* Link

batteries for EVs with some of the main players of the value chain, especially in the area of R&D and system integration (EU OEMs). In order to develop and strengthen capacity for future battery technologies, and to ensure Europe leads on next generation battery technology, the EU should -by 2025- set a goal to manufacture 10 GWh of advanced batteries with double the current energy density and half the current cost per kWh. This should be done by giving funding to 5-7-year-long consortia that[106]:

1. Build on the most promising advanced battery technologies and partner scientists with engineers from the outset to design pilot lines and start manufacturing small batches of advanced material.
2. As exemplified by Northvolt and Volkswagen, consortia should include at least one tier 1 supplier or premium car manufacturer that commits to buying the batteries once they meet the promised performance requirements. There is no path to success without such offtake commitment. We do not currently recommend mandating the use of these products, but the upcoming battery, car and other regulations will create opportunities to create more favourable market conditions for advanced batteries.
3. Where EU funding is given to support EU car or battery manufacturers to produce batteries, they should commit at least 20% funding of that to advanced battery production within the same capital investment cycle.
4. Consortia must be required to commit to manufacturing in Europe for the first phase until production scales up to at least 10 GWh. This should be a precondition of getting EU financing, will create European high tech and engineering jobs and secure a future industrial base.

It is key that strong collaboration between industry, non-profit (or research) and innovation actors is ensured and fits into coordinated strategies and programmes between Member States at European level while developing a skilled workforce with strong battery competences across the whole value chain.

6.4 Crude oil extraction and dependency

Lastly, in order to put an end to the EU's oil dependency and the negative impacts linked to oil extraction and use in transport, it is key that the EU and Member States urgently act on the following:

1. End all subsidies going to fossil fuels, including for oil;
2. End the exploration and extraction of oil in their territories as soon as possible;
3. Prevent imports of unconventional and risky sources of oil, such as tar sands oil, fracked oil or Artic oil;

[106] Transport & Environment (2020), *How Europe can win the battery race*. Link

4. Apply supply chain due diligence with strong environmental and social criteria to the fossil fuel industry.

7. Conclusion

Industrial processes linked to battery manufacturing have their toll on the environment but if we put into perspective the battery industry with the fossil fuel one, one cannot deny that - as pointed out in the media[107] recently - the two industries have been suffering from double standards. The oil industry has benefited for years from lax environmental standards, has fuelled wars and corruption and that, ultimately, once the fuel is burned, it is forever gone and causes long-lasting devastating effects in terms of climate change and air pollution.

Nevertheless it is imperative that the new EU battery regulation ensures that the processes used all along the battery value chain meet the highest environmental and social standards. By doing so it will guarantee no harmful chemicals end up in nature, make sure all batteries are recycled at the highest possible rate, with all processes along the battery value chain powered by clean energy. Such standards should soon enough be replicated in all supply chains and raw materials sourcing across the economy, with battery materials being the blueprint.

With batteries, the EU has the unique opportunity to move away from external raw material dependencies from other countries like it was for decades in the fossil fuel industry. This however can only be achieved if Europe invests in recycling and reuse potential, in improved chemistries that use less material and utilises smartly its available resources.

[107] The Guardian (13 December, 2020), *Electric cars are not perfect, but they are a good start*. Link

Annex

Assumptions

Passenger car energy efficiency (T&E LCA):

- Fuel consumption ICEs: 6 L/100km diesel, 7.5L/100km gasoline
- BEV energy efficiency: 0.175 kWh/km

Battery cell demand:

- Total car sales: from 2022 onwards, car sales in the EU+UK are at 2019 level (15.2 million)
- Average battery size:
  - BEV: from 50 kWh in 2020 to 60 kWh in 2030
  - PHEV: from 12 kWh in 2020 to 15 kWh in 2030
- Share of battery electric car new registrations: 21% in 2025, 54% in 2030, 100% in 2035
- Share of battery electric van new registrations: 20% in 2025, 50% in 2030, 100% in 2035
- Share of battery electric truck new registrations (>3.5t): 7% in 2025, 17% in 2030, 68% in 2035

Material requirements per kWh in 2020:

Element requirements (kg/kWh)	NMC111	NMC523	NMC622	NMC811	NMC9.5.5	NCA	NCA+	LFP	Average
Lithium	0.12	0.11	0.11	0.08	0.07	0.10	0.09	0.09	0.10
Cobalt	0.34	0.19	0.18	0.08	0.04	0.13	0.04	-	0.13
Nickel	0.34	0.47	0.53	0.64	0.66	0.70	0.71	-	0.48
Graphite	0.94	0.88	0.83	0.76	0.69	0.81	0.73	1.10	0.86
Manganese	0.32	0.27	0.17	0.08	0.03	-	-	-	0.16
Copper	0.36	0.34	0.32	0.29	0.27	0.31	0.28	0.43	0.33
Steel	0.36	0.34	0.32	0.29	0.27	0.31	0.28	0.43	0.33
Aluminium	0.62	0.58	0.55	0.50	0.46	0.55	0.50	0.73	0.58
Iron	-	-	-	-	-	-	-	0.69	0.08

Figure 17: Material requirements per kWh in 2020

Battery cell energy density (Wh/kg):

Wh/kg	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
NMC 1:1:1	193	201														
NMC 5:2:3	205	215	225	236												
NMC 6:2:2	217	228	239	252	266	282	288	296	303	311						
NMC 8:1:1	239	251	264	279	295	313	323	333	344	355	368	381	394			
NMC 9.5.5	263	277	292	309	329	360	372	385	399	415	429	444	460	476	493	510

Figure 18: NMW battery cell energy densities

Battery supply and demand: complementary analysis

Battery production capacity by origin of manufacturer

Thanks to an ambitious industrial strategy aiming at catching up with Asian battery producers on their territory, battery production capacity from European manufacturers could take over Asian ones in 2026. If achieved as planned, this is an important milestone given that today, according to 2020 data, around 98% of the batteries produced in Europe are made by Asian manufacturers. According to current production plans this share could drop from close to 100% today to 40% in 2025 and 26% in 2026 under the current factory plans.

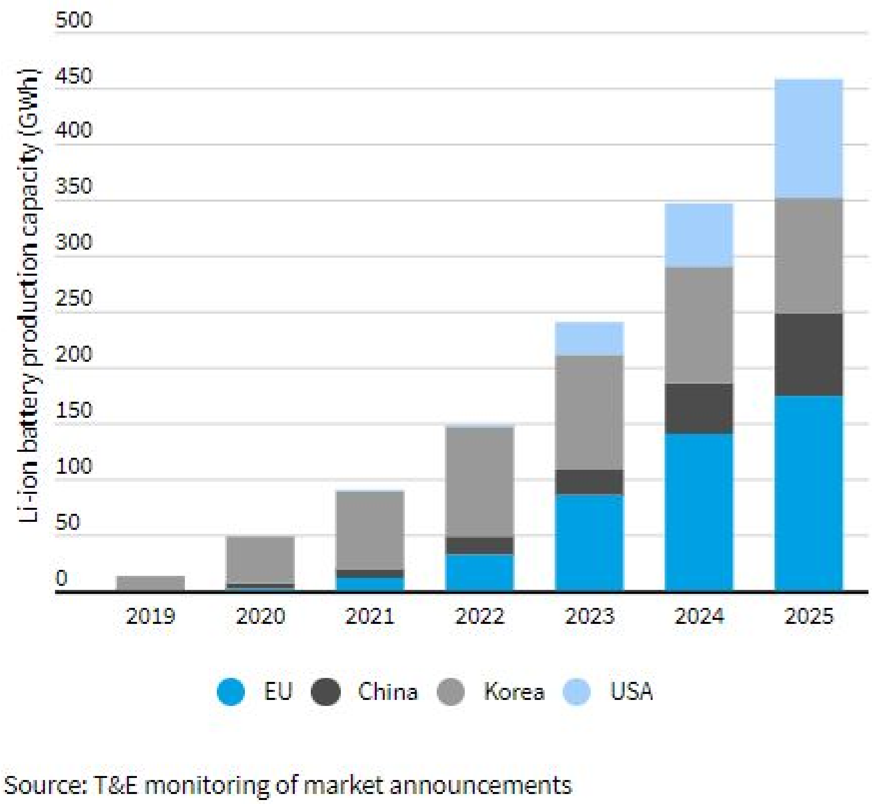

Figure 19: Li-ion battery production capacity in Europe, by origin of producer (GWh)

Job creation in battery manufacturing

According to an analysis by the Commission's Joint Research Center (JRC)[108], the estimated number of direct jobs created in battery cell manufacturing is on average 140 jobs per GWh produced per year (ranges between 90 and 180). This analysis is based on estimates from seven different battery production facilities, also taking into account high automation rates. With 460 GWh produced annually in 2025 and 730 GWh in 2030, this means there would be around 64,000 new direct jobs in battery cell manufacturing in 2025 and 100,000 in 2030.

On top of these high quality and future proof jobs from direct manufacturing, a significant number of indirect jobs are also created. These jobs are expected to be created in the immediate vicinity of the cell producing plant and include suppliers, subcontractors, logistics, mechanical engineering, construction and automation companies. Similarly, the JRC estimates the multiplication factor between the total number of jobs created along the complete value chain and the direct ones created in cell manufacturing to be in the range of 3.7 to 7.5 (mid value: 5.6). At European level, indirect jobs created from battery cell manufacturing would be around 360,000 in 2025 and 560,000 in 2030. We estimate that battery cell manufacturing has the potential to create about 420,000 future proof jobs in the EU from 2025, and 660,000 jobs from 2030.

Ambition of the car CO2 target and impact on the battery demand

In June 2021, the European Commission will propose to revise the current CO2 reduction targets for cars and vans. The current CO2 reduction targets for cars are at -15% in 2025 and -37.5% in 2030 (called Current Policies here) while the European Commission has hinted it could increase the 2030 target to -50% (called Enhanced 2030). The T&E pathway scenario is composed of T&E's recommended CO2 reduction pathway: -25% in 2025 and -65% in 2030.

The demand for Li-ion batteries necessary to produce the EVs that are needed to comply with the CO2 reduction targets can be delivered for each of these scenarios. T&E shows that the current -15% CO2 reduction for cars in 2025, could be met with around 125 GWh of batteries, which is only slightly more than a quarter of the total battery production capacity expected in that year (27%). In 2030, under the current scenario, around 300 GWh are sufficient to meet the EU targets (only 40% of total production capacity), while this could increase to 400 GWh if the target is increased to -50% (55% of total production capacity).

The fact that the demand for Li-ion batteries in these scenarios would be much smaller than the planned production capacity leaves much room to increase the CO2 reduction target both in 2025 and 2030 (see Figure 20). In the recommended T&E pathway scenario, under a -25% CO2 reduction target

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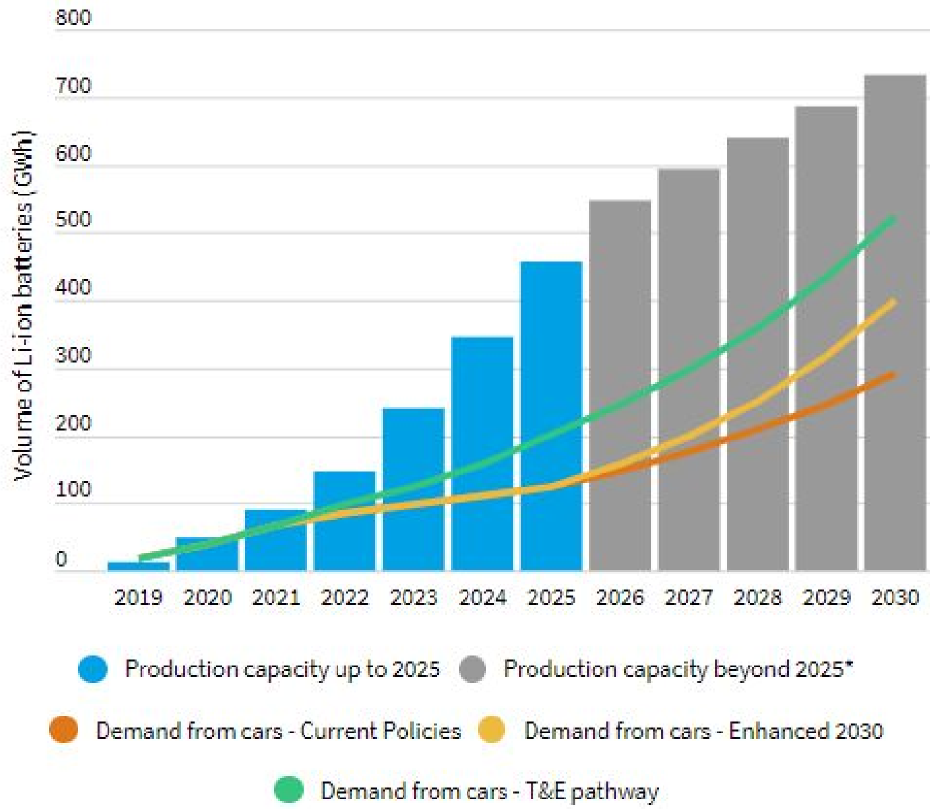
[108] Joint Research Center, JRC (2017), *EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions*. Link

in 2025 around 200 GWh is needed to comply with the target, which is 44% of the total production demand. If combined with a higher CO2 reduction target for vans as well (20% BEVs), then the cars and vans targets can be reached with half of the planned production capacity. In 2030, an increased target of -65% CO2 reduction would account for 525 GWh of battery, or 72% of the total production capacity (around 80% of total capacity when including vans at 50% BEV sales in 2030, corresponding to a 60% CO2 reduction).

Enough EU-made batteries for ambitious car CO2 reduction targets



The scenarios for demand in Li-ion batteries for cars are based on the following CO2 reduction targets: **Curent Policies**: -15% in 2025, -37.5% in 2030 (around 30% BEVs in sales in 2030); **Enhanced 2030**: -15% in 2025 and -50% in 2030 (around 40% BEVs); **T&E pathway**: -25% in 2025 and -65% in 2030 (around 55% BEVs).

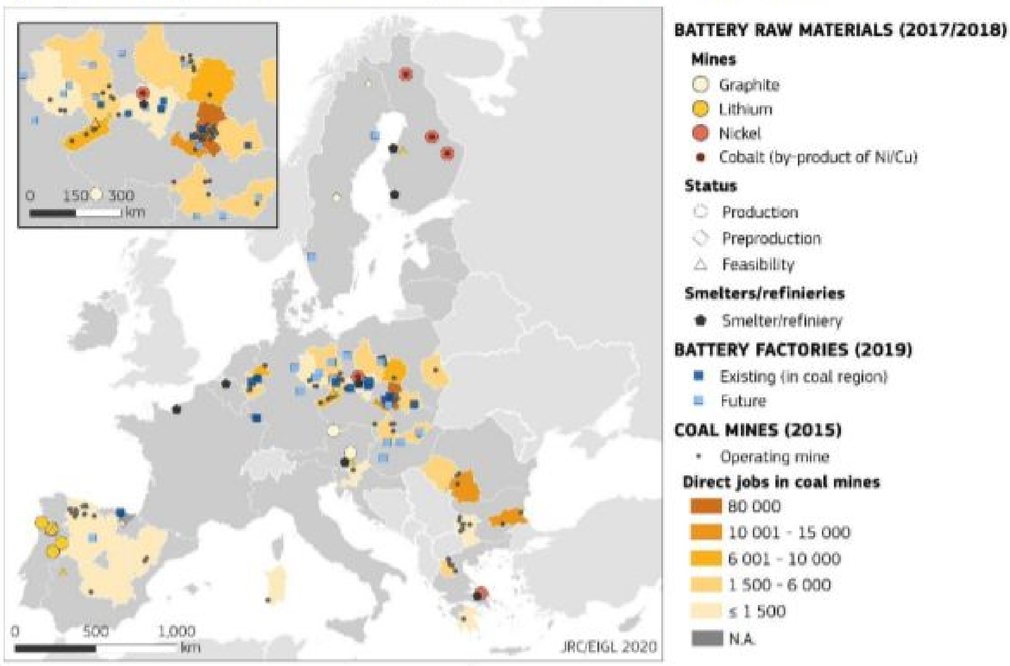
*Beyond 2025, the expected battery cell production capacity is more uncertain given most announcements are limited to a timeframe of several years.

Source: T&E monitoring of market announcements and T&E modelling of expected battery demand. Scope: EU27 + UK

Figure 20: Car CO2 reduction targets vs. battery production capacity

Socio-economic perspectives

In September 2020, European Commission added lithium to its list of critical raw materials[109] , underlined that mobilising Europe's domestic potential better is an essential part of the EU becoming more resilient and developing open strategic autonomy and highlights that geographical distribution of raw materials in Europe and the development of battery production provides interesting opportunities which could address some of the socio-economic challenges of the energy transition. Indeed as Figure X below shows, many EU battery raw material resources lie in regions that are heavily dependent on coal or carbon-intensive industries and where battery factories are planned. Many mining wastes are rich in critical raw materials and could be revisited to create new economic activity on existing or former coal-mining sites while improving the environment.



Source: Joint Research Centre

Figure 21: Battery raw material mines, battery factories and coal mines

The European Commission also underlines that the Just Transition Mechanism and the InvestEU fund should be used to help to alleviate the socio-economic impact of the transition to climate neutrality in

[109] Communication from the Commission on Critical Raw Materials Resilience (2020). Link

these regions by supporting their economic diversification through circular economy investments.

To strengthen this ambition to secure the supply of key raw materials, the European Commission has launched the **European Raw Material Alliance** in September 2020 which includes 150 companies as well as NGOs, associations and governments[110]. This alliance is set up on the same model and following the success of the European Battery Alliance in order to mobilise industrial and innovation actors and to help to help build out capacities and investment cases along the entire value chain, from extraction to processing and recycling.

European Battery Innovation - Member State breakdown

Following the success of the European Battery Alliance, the Commission has approved a second Important Project of Common European Interest ("IPCEI") to support research and innovation in the battery value chain, called "European Battery Innovation"[111]. The twelve Member States will provide up to €2.9 billion in funding in the coming years. In the table below the total number of projects selected is broken down per country. Italy is the leading country for the number of projects (21), Germany comes second (20), Austria third (8), Finland fourth (5) and Slovakia fifth (4).

[110] Speech by Vice-President Šefčovič at the launch of the European Raw Materials Alliance. Link
[111] European Commission, 26 January 2021, *State aid: Commission approves €2.9 billion public support by twelve Member States for a second pan-European research and innovation project along the entire battery value chain.* Link

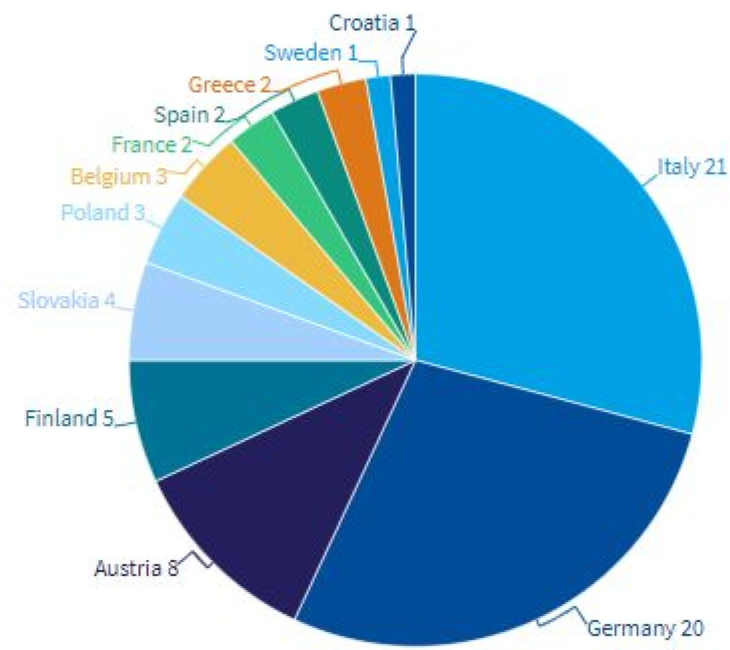


Figure 22: Number of projects under the 2nd IPCEI 'European Battery Innovation'

Solid state battery activities and perspectives in the EU

The largest interest in solid state batteries has been displayed by OEMs. According to a recent European Commission report, the final market-uptake could strongly depend on strategy decisions of OEMs. OEMs could launch solid state batteries as optional batteries in form of a premium option, which would also allow for low manufacturing volumes in the beginning. Many OEMs are aiming to get into the market with solid state batteries between 2022 and 2025.

- Volkswagen has invested in QuantumScape and aims to bring the first EVs with solid state batteries on the market in 2025
- BMW and Ford have invested in Solid Power. BMW aims to bring first EVs with solid state battery on the market in 2026
- Daimler is cooperating with Hydro-Quebec
- PSA Group participates in the ASTRABAT project on solid state, together with Umicore and Leclanché)
- Toyota is developing a joint venture on solid state with Panasonic (prime Planet Energy), focusing on

- Renault-Nissan Alliance and Hyundai-Kia invested in Ionic Materials (more than €5 billion invested)

Solid state batteries are a great opportunity for the EU to establish a next generation battery European value chain and the European Commission underlines that the EU has the best market conditions for the development of solid state batteries. The head start of other regions is very small and Europe still has chances to establish a competitive value chain, based on the existing networks and actors around materials, advanced manufacturing, battery engineering and the automotive sector (and relying on competencies for high precision, intensified automatisation and specialised machinery as well as geographic proximity with the automotive industry).

Based on the European Commission report, it is possible to see a market introduction of competitive solid state batteries by 2030, in case technical issues can be solved, sufficient investment made and industrial processes improved. The financial risks linked to the long-time horizon and uncertainties of payback in the time horizon, create the need for public investment and a roadmap of all relevant players for the commercialisation of solid state batteries.

Nonetheless, the EU is lacking innovative start-ups and SMEs trying to test solid state batteries on larger scale and real world conditions to finally enable the uptake of this technology. Existing projects and competencies at EU and national level should be bundled together via coordination of strategies and programmes between Member States and EU level aiming at commercialisation of solid state batteries.

According to the European Commission, there could be some applications of solid state batteries in niche markets in 3 to 5 years to demonstrate their advantages (e.g. wearables, drones or scooters), with hybrid electrolyte having the heist potential for future applications in the EV market and could reach maturity by 2030.

Transport electrification is where there are the most cost savings

The scale at which we are importing oil for transport and the great benefits of EVs versus ICEs in terms of economic dependency makes the transport sector the sector where there are the most cost savings to be achieved as we decarbonise the EU economy. A recent report from McKinsey shows that implementing clean technologies to decarbonise EU transport would cost €12 trillion from 2021 to 2050[112] making it the sector with the largest investment requirements (43% of total). However, these investments would ultimately result in lower operating costs: from 2021 to 2050, the EU would save an average of €130 billion annually in total system operating costs. According to McKinsey, it would take

[112] McKinsey (2020), *How the European Union could achieve net-zero emissions at net-zero cost*. Link

ten years to set up supply chains to support a switch to 100% EV sales, from mining the raw materials for batteries to assembling EVs.

Efficiency of battery BEVs vs. FCEVs[113]

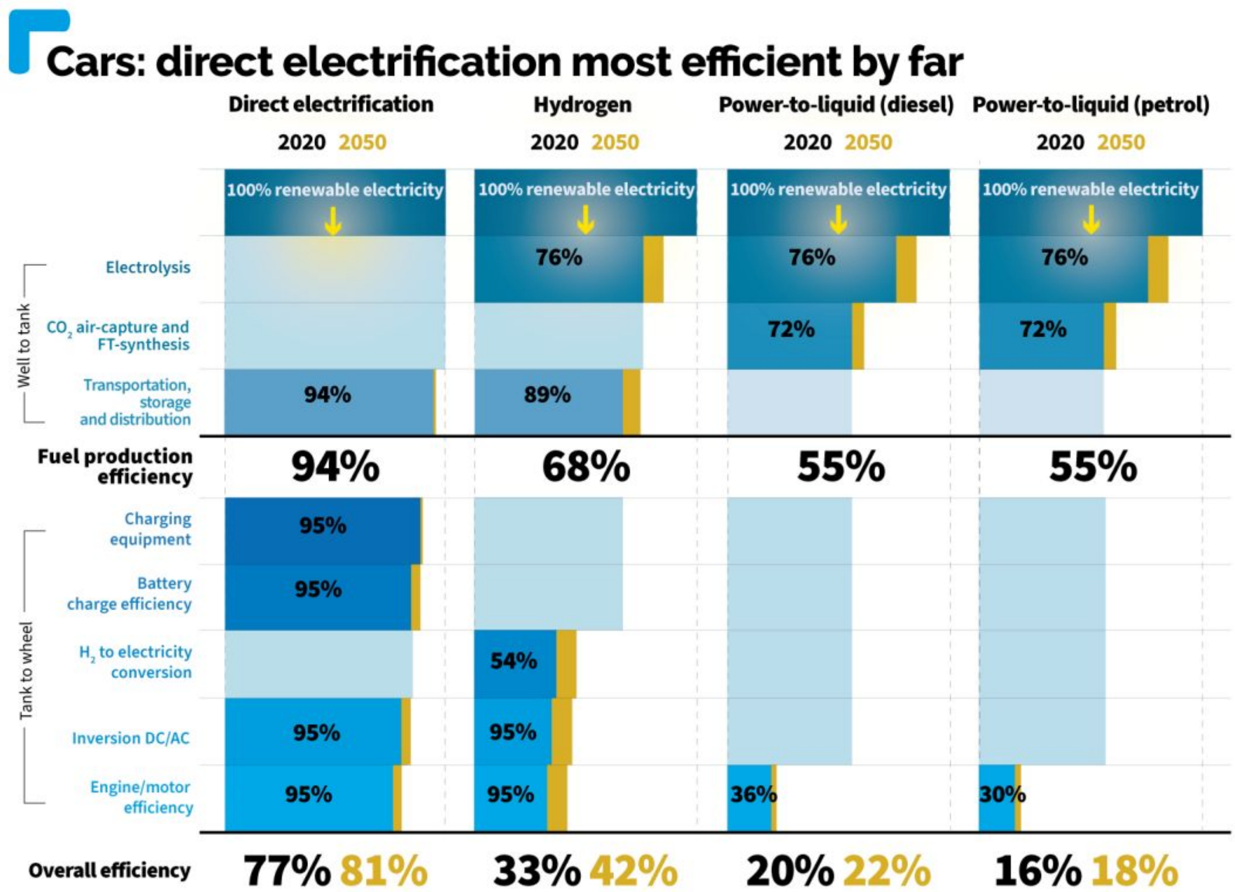


Figure 23: Energy efficiency comparison of different drivetrains

TCO comparison of BEV with ICE and HEV

[113] Transport & Environment (2020), *Electrofuels? Yes, we can … if we're efficient.* Link

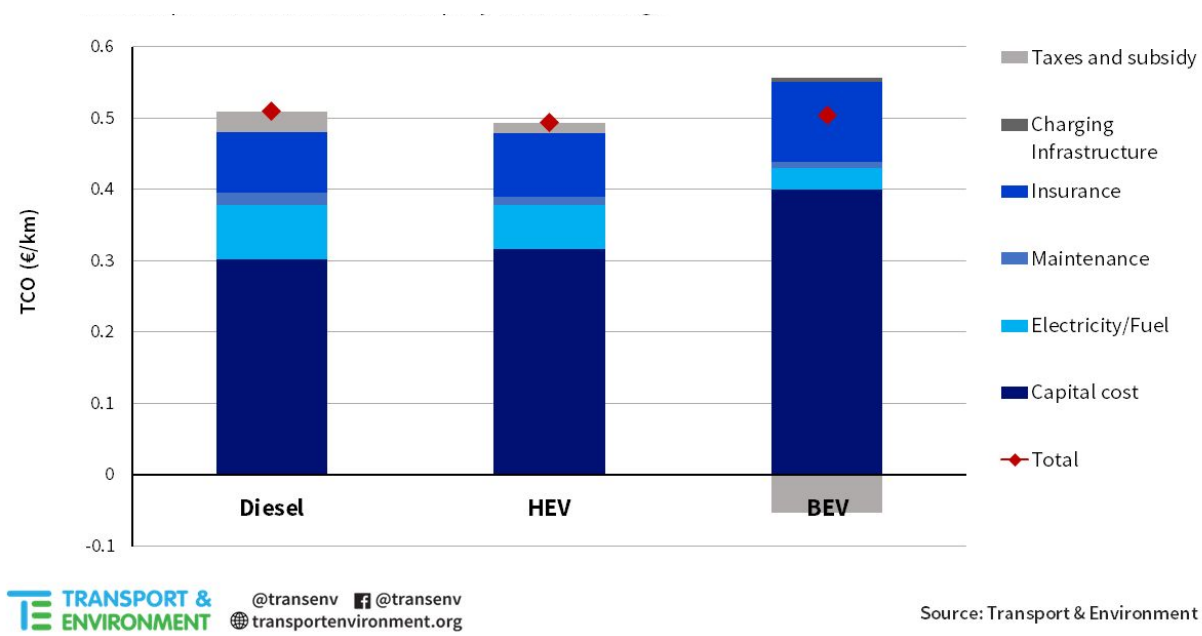


Figure 24: TCO comparison: BEV vs. diesel and HEV[114]

[114] Transport & Environment (2020), *Why Uber should go electric.* Link