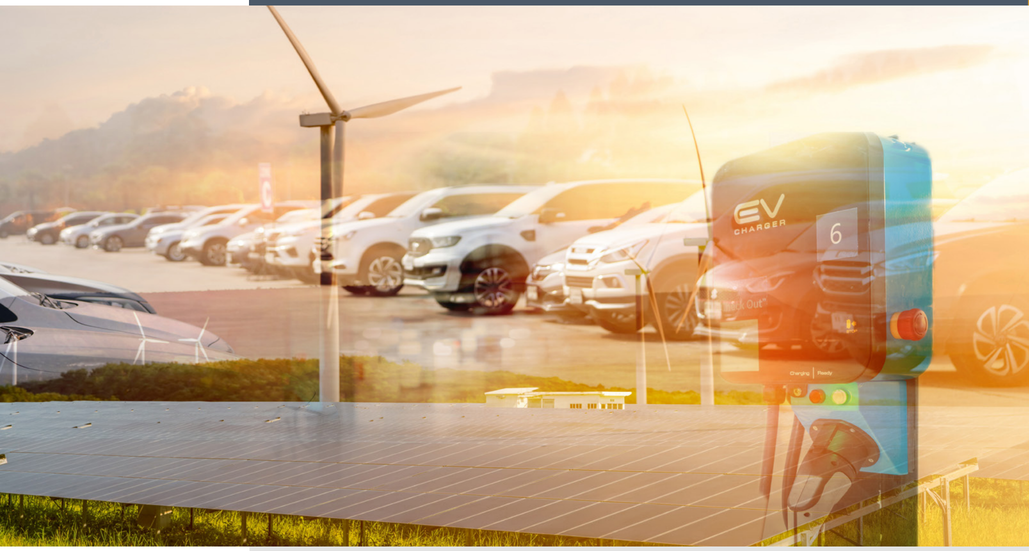

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Electric Vehicles: A Strong and Still Understated Performance

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Key Takeaways

- The manufacturing of electric vehicles (EVs) entails greater greenhouse gas emissions (GHG) than manufacturing conventional cars. GHG emissions from use, while dependent on the carbon content of the grid electricity, are significantly lower for EVs than for conventional cars. As a result, total GHG emissions are always lower for EVs..

- Many studies underestimate the ongoing decarbonization of electric grids in most countries. Taking it in account would further reduce the estimated GHG footprint of EVs. Moreover, EVs will facilitate the integration of renewable energy sources into the energy systems. Smart charging, based on the lower electricity costs of renewable energy, will allow EV owners to charge their batteries with low carbon electricity.

- Concerns have been raised that increased mining and metal refining efforts would entail growing energy needs and thus undermine EVs' climate performance. The reality is the opposite: technical improvements have allowed mining lower grade deposits with constant energy expenditures and expanded available reserves and resources.

One out of five cars sold worldwide in 2023 were electrified–most of them full-electric, the remainder plug-in hybrids. The trend seems ready for an acceleration in 2024 as new models costing less than 25,000 euros will hit the roads. Massive investments in battery manufacturing take place throughout the European continent and in the Americas, while the European Union (EU) has decided that new internal combustion engine cars will be prohibited from sale in 2035. In this context, the climate benefits of electric vehicles (EVs) are regularly put in doubt.

Electric vehicles are better for the climate – even in worst-case scenarios

Across its life cycle, a typical European electric car produces less greenhouse gas (GHG) and air pollutants or noise than its petrol or diesel equivalent. Emissions are usually higher in the production phase, but these are more than offset over time by lower emissions in the use phase. According to the European Environment Agency's report on electric vehicles, life cycle GHG emissions of EVs are about 17-30% lower than those of petrol and diesel cars.[1]

More specifically, the manufacture of EVs results in higher carbon dioxide (CO_2) emissions than in the case of classical internal combustion engine (ICE) cars. This is due mainly to the extraction and refining of the metals–often with high-temperature heat–that enter the composition of batteries: "Building the 80 kilowatt-hour (kWh) lithium-ion battery found in a Tesla Model 3 creates between 2.5 and 16 metric tons of CO_2–exactly how much depends greatly on what energy source is used to do the heating", according to the Massachusetts Institute of Technology, summarizing a range of different studies.[2]

Then, EVs enable CO_2 emission savings by not burning petroleum products and using only grid electricity for propulsion. Hence, the actual CO_2 savings depend on the carbon content of that electricity. In Norway, where the electricity comes almost 100% from hydropower, EVs have a very low carbon footprint over their life cycle. In countries where the electricity comes almost exclusively from coal plants, the climate advantage of electric cars is indeed small. But one must make rather unrealistic assumptions of a very short distance traveled by a car over its technical life to show greater emissions from an EV compared to its "thermal" counterpart.

While some think tanks do so to defend the oil business, all serious analyses acknowledge at least some better climate performance of EVs over ICE vehicles. According to the Agency for Energy Transition (ADEME), an electric car has a carbon footprint two to three times lower than a similar thermal car, provided it is equipped with a "reasonably

1. "Electric Vehicles from Life Cycle and Circular Economy Perspectives", Transport and Environment Reporting Mechanism (TERM) Report, No. 13/2018.
2. A. Moseman, "Are Electric Vehicles Definitely Better for the Climate Than Gas-powered Cars?", MIT, Climate Portal, October 13, 2022, available at: https://climate.mit.edu.

sized battery providing up to 450 kilometers range (WLTP).[3]

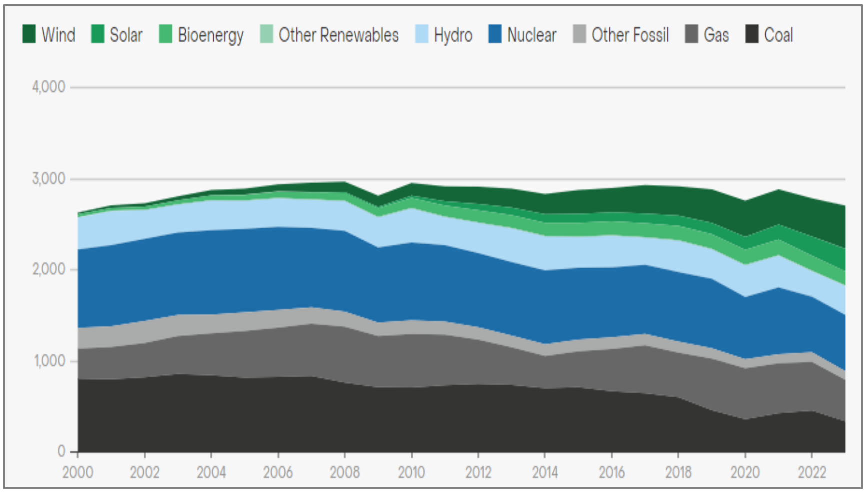
The global electricity generation is decarbonizing faster than one thinks

Many studies, however, are based on current electricity mixes and carbon content of the average kilowatt-hour. These analyses do not account for the rapid decarbonization of the electricity mixes that will happen in the next two decades. A car hitting the roads in 2024 may still be there in 2043 or later: the average retirement age for used cars is 19 years in France (18 years in Western European countries, 28 years in Eastern European countries).

Meanwhile, the carbon-intensive electricity mixes in European countries will likely get largely decarbonized. In 2023, for the first time, renewable energy sources produced over 40% of the EU's electricity (44% more precisely, with wind and solar representing 27% of the electricity). Moreover, 23% of the EU's electricity comes from nuclear power. This led to a decrease of 19% in both fossil electricity generation and CO_2 emissions year-on-year. Coal power generation was lower than 13%, gas power generation lower than 17%–and lower than wind power for the first time (see Figure 1).

These trends will continue and even accelerate. The EU has set a target of 42.5% of its final energy consumption from renewable sources by 2030, which will likely require electric renewables to deliver over 65% of power generation. With nuclear power, low-carbon electricity generation would thus reach 90% in just six years in Europe. As a result, the CO_2 emissions resulting from these vehicles' electricity consumption will reach very low levels, as they already do in France.

Figure 1: Electricity generation in the EU by sources, 2000-2023



Source: Ember Electricity Data Explorer.

3. "Voitures électriques et bornes de recharge – Les Avis de l'Ademe, octobre 2022". WLTP stands for "Worldwide Light Vehicles Test Procedures", available at: www.librairie.ademe.fr.

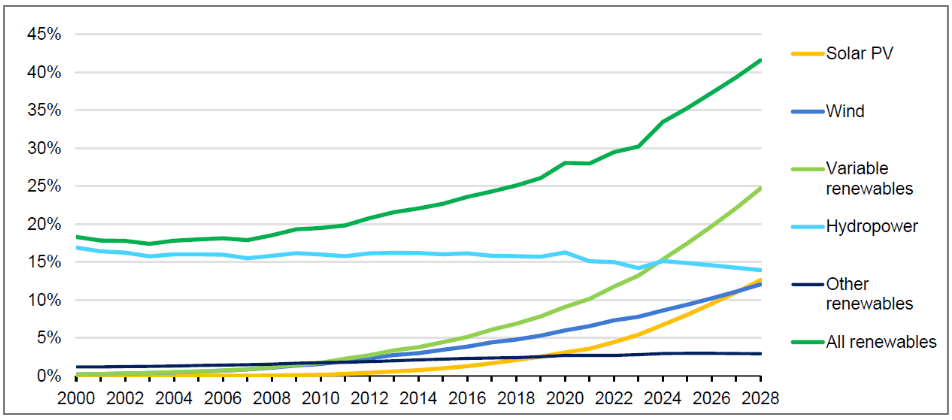
According to the European non-governmental organization (NGO) Transport & Environment, the worst case in Europe (battery produced in China, charging in Poland) would lead to a life-cycle analysis of CO_2 emissions of 150 gCO_2/km[4] for mid-sized cars, and the best case to LCA CO_2 emissions of less than 50 gCO_2/km, to be compared with roughly 250 gCO_2/km for a similar "thermal" car. The EU average would be 80 gCO_2/km,[5] three times cleaner than a conventional car. With less favorable assumptions regarding the total distance covered by all vehicles during their lifetime, one can still assert that EU average LCA emissions of electric cars will be less than 100 gCO_2/km.[6]

The trend towards decarbonization of electricity mix is not a European exclusivity. The acceleration of deploying renewable energy sources, notably solar and wind, is global. COP-28 has called for a tripling of renewable energy by 2030. The global renewable electric capacities increased by over 500 gigawatts (GW) in 2023 alone, reaching over 4,000 (GW). A tripling from the end of 2022 level would lead to roughly 11,000 GW capacity. This would increase renewable electricity generation from about 8,500 terawatts-hour (TWh) in 2022 to 25,000 TWh in 2030, that is, almost 60% of global electricity generation[7]–consistent with the International Energy Agency (IEA) "Net Zero by 2050" scenario.[8]

However, current projections of renewable energy deployment based on current policies fall short of the tripling goal: under existing policies and market conditions, the IEA forecasts that global renewable capacity will reach 7,300 GW by 2028. This growth trajectory would see global capacity increase to 2.5 times its current level by 2030. Governments can close the gap by overcoming various challenges: policy uncertainties, insufficient investment in grid infrastructure, cumbersome administrative barriers and permitting procedures, and insufficient financing in emerging and developing economies.

4. More precisely, CO_2 "equivalent" to take account of all GHGs.
5. "Update – T&E's Analysis of Electric Car Lifecycle CO_2 Emissions", Transport & Environment, June 2022, available at: www.transportenvironment.org.
6. C. Philibert, *Pourquoi la voiture électrique est bonne pour le climat*, Les Petits Matins/Institut Veblen, 2024. Another difference is that Transport & Environment gives a CO_2 credit to the fabrication of EVs, associated with the perspective of recycling its materials at the end of its life. This credit represents the difference between the CO_2 emissions that would have resulted from the use of new, primary materials, and the lower amount of emissions that will effectively occur in producing a novel battery with recycled materials. However, while the initial emissions from mining and refining materials could be spread over multiple successive vehicles, this credit does not represent actual negative emissions.
7. "Renewables 2023, Analysis and Forecast to 2028", IEA, 2024, available at: www.prod.iea.org.
8. "Net Zero Roadmap, 2023 Update", IEA, September 2023, available at: www.iea.org.

Figure 2: Global electricity generation by technology, 2000-2028

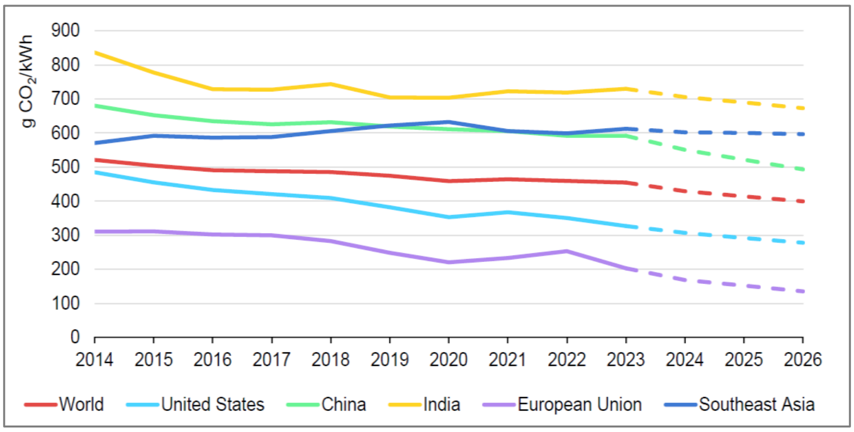


Source: IEA, Renewables 2023.

However, if governments do not close these gaps, renewable energy will nevertheless deliver over 40% of global electricity generation by 2028 (see Figure 2). Meanwhile, global nuclear generation is expected to reach a new historical high in 2025, exceeding the previous 2021 record. This is supported by the continued recovery in French nuclear output, restarts in Japan, and new plants coming online in various parts of the world, half of them in China and India.[9]

Constrained by the rapid deployment of renewables and the persistence of nuclear power, fossil fuels will generate less than half of global electricity by 2028, against two-thirds in 2017. Coal would be hit the most, and renewables will overtake coal as the largest supply source in 2025. Hence, the IEA forecasts an average decline of 4% in CO_2 intensity in the coming years. The highest rate of progress in reducing emission intensity will occur in the EU, followed by China, then the United States and India (see Figure 3). This means that emissions savings via the electrification of transport, as well as that of heating and industry, will become even more substantial.

Figure 3: CO_2 intensity of electricity generation, 2014-2026



Source: IEA, Electricity 2024.

9. 2024, *Electricity 2024, Analysis and Forecast to 2026*, IEA, available at: www.iea.org.

The forecast decline in the carbon intensity of electricity generation is particularly spectacular in China. China has played a significant role in global energy trends, being the dominant player in coal markets and absorbing almost two-thirds of the rise in international oil use. But China's economy is reaching an inflection point. A saturation of infrastructure will lower future demand in various energy-intensive sectors. Its total energy demand approaches its peak.[10]

China commissioned 2023 as much solar photovoltaics (PV) capacity as the entire world did in 2022, while its wind power capacity additions also grew by 66% year-on-year. The strong expansion trend of renewables is expected to result in renewable generation growing by around 20% in 2024, assuming a recovery in hydropower, and 13% on average in 2025-2026, covering all the additional Chinese demand growth and suppressing coal-fired output. China has built many coal-fired power plants, but their utilization rate is now less than 50% and will reach about 35% by 2030.

China commissioned in 2023 as much solar PV capacity as the entire world did in 2022

China is the powerhouse of renewables for the entire world and gives no sign of slowing. The Chinese PV module manufacturing capacity will soon reach 1,200 GW per year, three times the global installations, in 2023. If China and other countries ramp up in the next few years the installation of solar PV up to 70% of this manufacturing capacity, i.e., 800 GW/year, more coal could be displaced, and by 2030, global CO_2 emissions from the power sector would fall by 30% from 2022 levels. At one condition though: that this variable electricity is smoothly integrated into the power systems.

This is where the EVs step in.

Batteries allow electric vehicles to take advantage of low-carbon electricity

Besides existing trains, metros, tramways, and trolleybus that are continuously connected to the grid, the new generation of EVs is defined by their electric storage capacity, i.e., their batteries. While their fabrication entails additional CO_2 emissions, their use allows for even more CO_2 reductions, as considered above. Most of them are individual vehicles, which are on the roads and streets one to two hours per day usually. This means they could be connected to the grid when at a standstill, for over 22 hours a day, provided it is feasible to stay connected to the grid in terms of available infrastructure. This could take place in homes, usually at night, but also in offices or industries, universities, malls, etc., during the daytime.

10. *World Energy Outlook 2023*, IEA, 2023, available at: www.origin.iea.org.

As such, they can serve multiple purposes: ensuring the desired range of the vehicle, of course, but also preferentially withdrawing electricity from the grid at times of excessive production–which is called smart charging. Time-based price signals should be given to EV users, reflecting the variations of the marginal costs of electricity generation every hour or even shorter time, possibly with some automatism. This would ensure that the electricity effectively charged in the batteries is significantly less carbon intensive than the average electricity because the marginal costs of renewable electricity are close to zero. In contrast, the marginal costs of fossil-fueled power plants incorporate fuel costs.

The flexibility provided by the batteries of EVs can be increased with bidirectional charging or "vehicle-to-grid" capability (or "to-home" or "to load", sometimes summarized in "vehicle-to-X"). If all 40 million private cars in France were electrified with a 50-kWh battery, this would represent 2 TWh of battery storage, or the energy of a solar farm with a capacity of 200 GW during 10 hours at full power.

Obviously, not all private cars will be available for smart charging and vehicles to the grid in the middle of the day or at night after the usual evening demand peak. Still, they will help flatten the daily fluctuations of solar and/or wind electricity generation. In so doing, they will support the deployment of relatively more renewable capacities. At the same time, they will reduce the carbon content of the electricity they use. In total, their batteries will contribute in two distinct ways to the decarbonization objectives.

Hence, LCA studies of EVs should be considered as expressing an upper limit to their carbon footprint rather than their carbon footprint itself.

The electrification of transport increases the demand for some metals, but the overall impact on metal extraction is lower than assumed

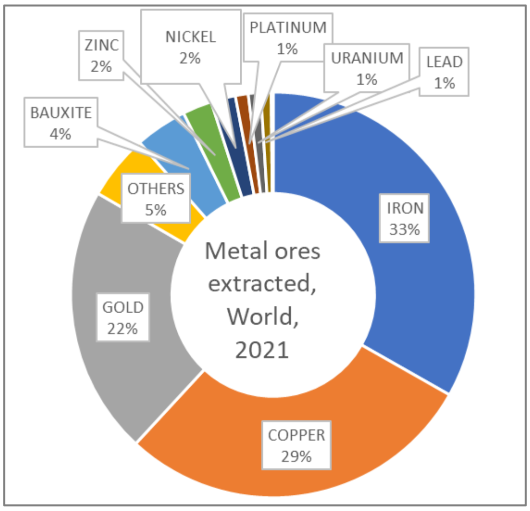
The energy transition necessary to effectively mitigate climate change includes a considerable increase in renewable energy capacities, notably electric, and the electrification of many end uses in the building, industry, and transportation sectors. Arguably, this leads to an increase in the demand for metals. Renewable energy capacities use metals; they need relatively larger power grids, themselves metal intensive, and some of the electrified end-uses also require more metals than their "fossil fuel" counterparts.

This is particularly the case of EVs. Equipped with a 75-kWh lithium-ion battery with "NMC 622" ternary cathode (60% nickel, 20% manganese and 20% cobalt) and graphite-based anode, an electric car needs twice as much copper and manganese than a conventional car, plus some lithium, nickel, graphite, and cobalt–in total 200 kg of metals vs. about 40 kg (steel and aluminum apart) for the conventional car. Therefore, the mineral demand for clean energy technologies would rise at least four times by 2040, with particularly high growth for EV minerals.[11]

This has led some observers to issue misguided alarms. They misread a graph the IEA presented in 2021, interpreting the numbers on this graph as multipliers of the whole demand for these minerals in 2020, while they represented the increased demand for these minerals only from clean energy technologies.[12] In fact, they are utilized in many other sectors, so the increase in total demand will be much less.

Still, some have stated that the extraction of metals will be multiplied by 4 to 5 in the coming years. This is not the case. The bulk (80%) of the extraction effort for metals, measured by the tonnages of rocks moved, is devoted to three metals only: iron, copper, and gold (see Figure 4). Considerable differences in the metal-to-rock ratios lead to wide differences in amounts of metal extracted each year: over one bn tons of iron, 21 million tons of copper, and 3,000 tons of gold. All other metals are minor in comparison, and some (cobalt, for example) are usually collected as co-products or by-products of iron or copper. The energy transition will not increase the demand for gold; it will increase the demand for iron (precursor of steel) by a few percent and increase the demand for copper by 25% to 35%.[13]

Figure 4: Global extraction of metal ore concentrates and compounds, 2021



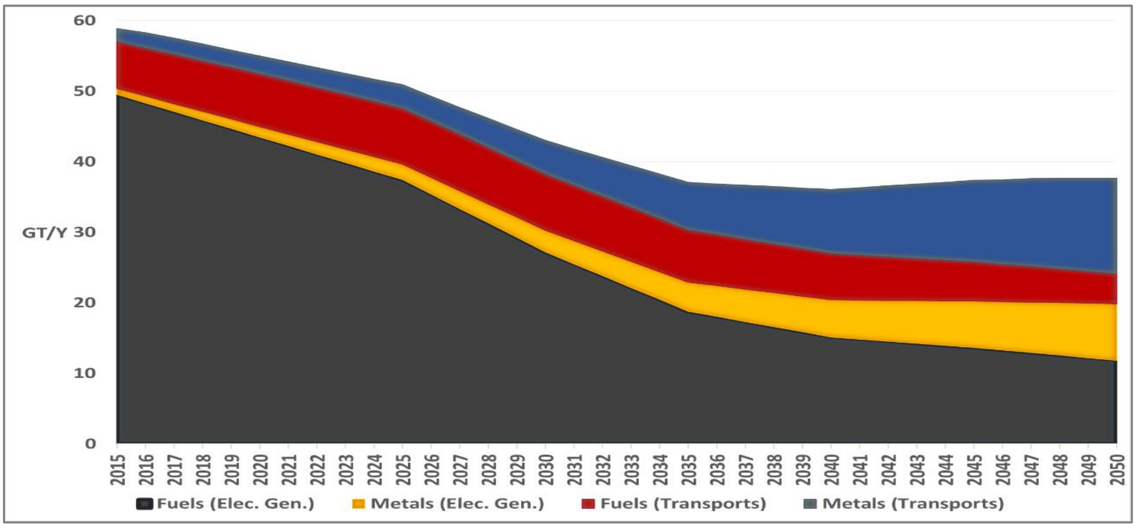
Source: data from WU Vienna (2023): Raw Material Profile for Metal ores.

Scientists have observed that the energy transition will globally reduce, not increase, the extraction effort if one considers the fossil fuels and the metals (excluding non-metallic minerals) for both electricity generation and transportation. For example, Watari

11. "The Role of Critical Minerals in Clean Energy Transitions", *WEO Special Report*, IEA, May 2021, available at: www.iea.org.
12. *Ibid*, p.9
13. *Ibid*, p. 134.

and colleagues from the Japanese National Institute for Environmental Services[14] have computed the total tonnages of rocks removed for metal and fossil fuels extraction from 2015 to 2050 (excluding non-metallic minerals), showing a global decrease, thanks to the important reduction in the extraction of coal (see Figure 5). Nevertheless, if one looks only at transport, the total extractive work will increase significantly with the electrification and increased metal demand.

Figure 5: Overall rocks removals for transport and electricity generation



Source: After Watari et al.*, 2021.*

Mining can be extended with constant energy costs and decreasing CO_2 emissions

How bad is this? The mining industry can be detrimental to the environment. However, this depends very much on the policy of the mining companies and the control of the government, the NGOs, the media, and public opinion. In any case, there is an impact, and one can prefer to minimize the mining efforts for the sake of landscape, biodiversity, or prevention of water, soil, and air pollutions. The exploitation of nickel in Indonesia and of cobalt in the Democratic Republic of Congo are often mentioned as significant environmental or social issues relating to mining.

14. Watari *et al.*, "Sustainable Energy Transitions Require Enhanced Resource Governance", ScienceDirect, August 20, 2021, available at: www.sciencedirect.com.

However, the technical evolution of batteries has not come to an end–far from it. While most batteries in EVs are still of the "ternary" type with cobalt, manganese, and nickel, the share of lithium iron phosphate (LFP) batteries is increasing fast. It now represents 1/3 of the global battery market. Their lower cost and longer technical lifetime make LFP batteries the technology of choice for light- and heavy-duty vehicles.

The technical evolution of batteries has not come to an end–far from it

The possible exhaustion of resources is a widespread concern. The declining grade of some heavily exploited minerals, such as copper, is usually presented as proof that exhaustion is forthcoming soon and that further extraction will require ever-increasing amounts of energy. Hence, over time, the manufacturing of batteries would require increased amounts of energy, entailing increasing CO_2 emissions and further reducing the climate benefits of electric vehicles.

The reality is very different. If one considers copper, for example, probably the most essential metal for the energy transition, including for EVs, technical improvements and economies of scale have led the mining industry to be able to exploit large, low-grade deposits (typically 0.7% of copper content) with energy expenditures very comparable to those that were necessary half a century ago to exploit smaller, higher-grade deposits (typically 1.7% of copper).[15] The diminution of the grade, instead of proving the imminence of the exhaustion, has led to an increase in the reserves and resources accessible with comparable effort, for there are many more (and larger) deposits with low grades than deposits with high grades. Fifty years ago, economically exploitable copper reserves were assessed at 280 million tons (Mt), and copper "resources" (not immediately exploitable) were estimated at 1.6 billion tons (Gt). Since then, 650 Mt of copper have been extracted; the reserves are now assessed at 890 Mt, and the known resources at 2.1 Gt, while "undiscovered" resources are estimated at 3.5 Gt based on "indirect geological evidence".[16]

Meanwhile, the energy used for mining and refining metals is getting progressively electrified and decarbonized, as the introduction of battery or catenary "haul trucks" illustrates. Moreover, recycling will gradually scale up as the availability of used batteries grows. During the next two decades, the rapid deployment of EVs may not allow for significant amounts of battery materials to come from recycling. However, when the market growth slows, the share of recycled materials will progressively increase, thereby further reducing the energy consumption and associated GHG emissions for manufacturing new EVs.[17]

15. N. Rötzer and M. Schmidt, "Historical, Current, and Future Energy Demand from Global Copper Production and Its Impact on Climate Change", *Resource*, vol. 9, n° 4, MDPI, 2020.

16. "Mineral Commodity Summaries 2023", United States Geological Service (USGS), 2023; J. M. Hammarstrom *et al.*, "Assessment of Undiscovered Copper Resources of the World", USGS, 2015.

17. M.-A. Eyl-Mazzega, D.-P. Gherasim, C. Vannier and A. Contu, "How to Meet the Industrial Challenge of Electric Mobility in France and in Europe"¸ *Notes de l'Ifri*, Ifri, November 2023.

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