August 2024

EVS FOR ALL

PART 1 - A HISTORY OF EVS AND CURRENT MARKET ANALYSIS
PART 2 - EVS' IMPACT ON POWER SYSTEMS AND SUPPLY CHAINS

Dr Lars Schernikau

CONTENT

1. Intro - EVs' impact on power systems and supply chains

Globally, the EV narrative is gaining momentum, with over 16 million EVs, including hybrids, expected to roll off production lines in 2024 alone. This represents almost 20% of global car sales. Yet, these figures represent just a minority of the total global vehicle fleet of almost 1.5 billion (Figure 1: Global vehicle fleet), highlighting that we are only at the start of this "revolution" …or are we?

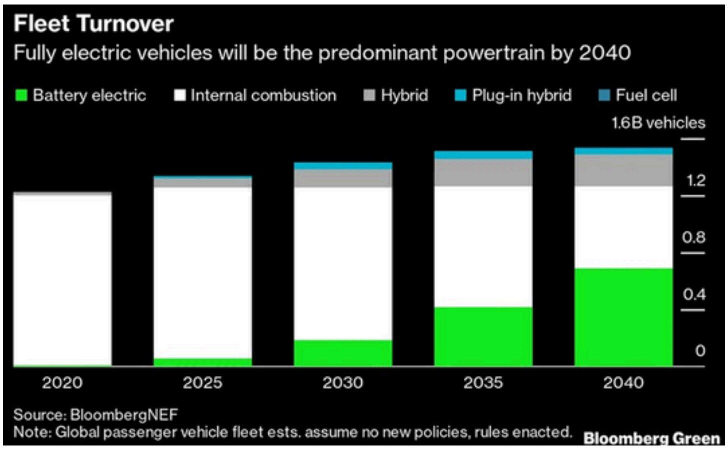
The electric motor is amazing. Its "invention" in the early parts of the 19th century involved **Faraday, Jedlik, and many more. Also Orsted, Ampere, Maxwel, Herz, Tesla, Westinghouse** and so many other famous names, with companies still carrying their names, are instrumental to today's understanding of electricity and the motors or engines they power.

Following the first law of thermodynamics and electromagnetism, an electric motor "simply" converts electrical energy into mechanical energy. Btw, a generator in a power plant is principally an electric motor working the other way around, converting mechanical energy into electrical energy.

In physics, electromagnetism is an interaction that occurs between particles with electric charge via electromagnetic fields. The electromagnetic force is one of the four fundamental forces of nature (gravity, electromagnetism, weak force, strong force).

The development of the internal combustion engine (ICE) using oil-based liquid fuels took place more or less in parallel and took off in the 2nd half of the 19th century with inventors such as **Nicolaus Otto, Gottlieb Daimler, Wilhelm Maybach, Karl Benz, Rudolf Diesel**, and many more. The application of combustions engines went of course far beyond transportation but seemed to always be focused on making "driving machines". This was the case because of the versatility and easy transportability of the liquid hydrocarbon fuel (petrol or diesel) they used.

Figure 1: Global vehicle fleet forecast until 2040



Sources: Bloomberg, June 2022- Link in Links and Resources below

Because carbon adds its own significant energy to the mix with hydrogen, gasoline (a hydrocarbon) has ~3,5x higher volumetric energy density (joules per litre) than liquid hydrogen, *and ~7x higher density than compressed H2, as envisioned for H2-powered cars. Only a few solids have a higher volumetric energy density than gasoline, which explains its wide use for transportation.* **(Schernikau from "The Unpopular Truth… about Electricity and the Future of Energy")**

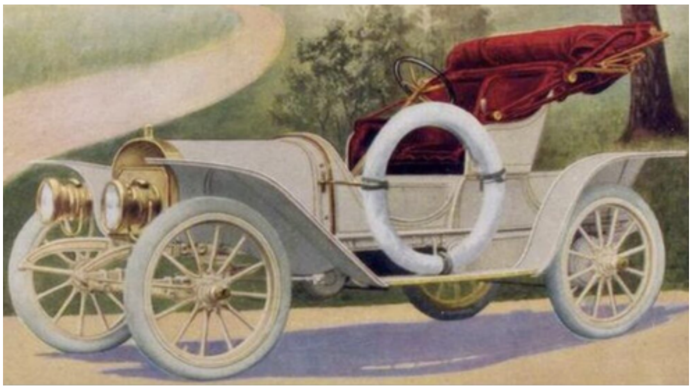
Electric motors always had a much wider use case than transportation. In fact, electric vehicles (EVs) appeared rather secondary. Electric motors were used for an array of industrial and consumer applications, but always requiring an external power source, connected by a wire (see modern trains). For "wireless" transportation electric motors always required (1) sufficient electricity and (2) a battery to "carry" the electric energy.

When it comes to transportation, the principal difference between EVs vs internal combustion engine vehicles (ICE) appear obvious:

- The combustion engine uses highly energy dense petrol or diesel fuels produced from crude oil and converts this chemical energy into motion.
- The "wireless" Electric Vehicle requires a battery, which needs to be charged first to then convert electrical energy into motion.
- The conversion process within the vehicle (fuel to motion, vs electricity to motion) is much more efficient in an EV. The question is what happens before that?

Let's consider that liquid fuels and electricity are "free" as an "input" for both the Electric and ICE vehicles, it is then important to note that in transforming the input energy into mechanical forward motion, ***an electric engine is up to three times more "efficient" than a combustion engine*** (Sciendo 2020). This has to do with the thermal energy "lost" in the combustion process. ***There is a reason why today's trains run on electricity and not on diesel anymore.***

Figure 2: LowTechMagazine 2010



Sources: Link in Links and Resources below

This apparent "conversion efficiency" also appears to be the basis for today's push for EVs, coupled with the hope of practically unlimited "clean" electricity from wind and solar… what could be more obvious than to switch from combustion vehicles to electric vehicles? Well, let's have a look… as always, in regard to energy, things are rarely simple and easy.

Part 1 focuses on the history and market overview of EVs. Part 2 focuses on EV's impact on power systems,raw material supply chains, and safety concerns, plus explore the future.

By the way, I have to admit that I am not covering, but not forgetting, the important contribution of the steam engine. The steam engine is worth a whole chapter on its own, but since the steam engine is currently not "competing" with EVs, it is not covered here.

1.1 EV a short history

One hundred years ago electric cars were a common sight on city streets of Europe and the United States. Many of them had a range comparable to that of today's EV's.

Early EV manufacturers and battery makers could not agree on how to position the electric vehicle in the market. Some were convinced that "the electric" should be marketed as a short distance city vehicle. They saw it as a mistake to try and sell electric cars as a touring vehicle, because its range would always be inferior to that of a gasoline powered car.

Instead (like today), they focused on the fact that the range of electric cars was sufficient for most people and that the cars were supposed to replace standard ICE vehicles.

The range of electrics was also demonstrated by setting hypermiling records during staged events, in which electrics were run at slow and constant speed over carefully selected roads using special tires.

Already in 1899, two American engineers covered 100 miles (160 km) on a single charge. In 1909, Emil Gruenfeldt of the Baker Motor Vehicle Company covered 161 miles (260 km) on a single charge in his Baker Electric Roadster. Two years later, he beat his earlier mark by travelling 202 miles (324 km) without recharging the batteries.

Data of French record runs, name a range of 191 miles (307 km) as early as 1901, set at an average speed of 17 km/h by Louis Krieger, a record that stood until 1942.

In 2009, the Tesla Roadster set a new hypermiling record for electric vehicles: 311 miles or 501 km on a single charge. This result was obtained at a speed of 55 km/h.

In 1909 "Electrical World" wrote: "The average EV, as built today, has considerably more available mileage on one charge of battery than the average vehicle of ten years ago, and what is more, has a considerably greater mileage than is actually needed in the run of business or pleasure, except where a long tour is undertaken."

It seems that 120 years ago we were already where we are today, so what has changed?

1.2 The current EV market

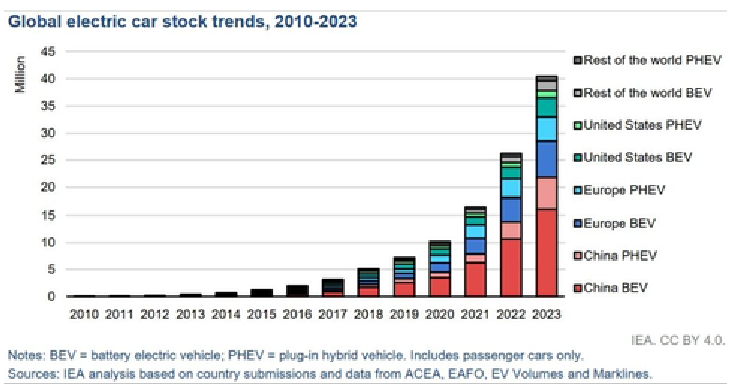
Driven by vast global subsidies and government support programs, sales of electric vehicles reached another milestone in 2023 with 14 Mln EVs sold. Electric and hybrid cars apparently accounted for about 18% of all cars sold in 2023, up from a 14% share in 2022 and just 2% in 2018. Nearly one in five new cars sold in 2023 was electric/hybrid and although more than 90% of sales were in China, Europe, and the United States, China led the way with almost 60% of total sales with Europe at nearly 25% (IEA World Energy Investment – Link in Links and Resources below)

The total "electric" globally fleet consisted of just over 40 Mln vehicles, counting less than 30 Mln actual EVs, the others are plug-in hybrids (Figure 3: Electric and Plug-in vehicle stock), which I don't consider an Electric Vehicle, I drive one myself from time to time and can tell you they are about optimizing fuel consumption (which is great), but not about replacing combustion engines. China is at the forefront of the electric vehicle (EV) market, demonstrating significant diversification. Major companies like BYD are setting new production standards, pushing traditional leaders such as Tesla into a smaller market share.

The top 15 car manufacturers collectively produce 80% of the world's EVs. Among these, Chinese company BYD is the clear leader in sales and continues to grow (see 4: Figure EV Sales).

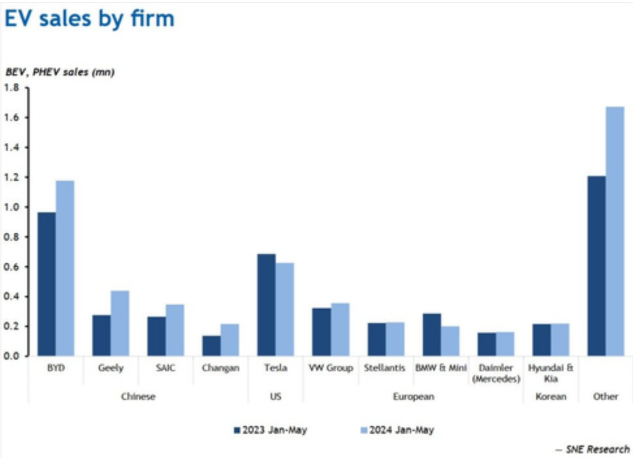
Meanwhile, Tesla's share of global EV sales has declined to less than 15% in the first half of 2024, although it maintains a larger installed base. Despite this, Tesla is gradually losing market position (see Figure 5: EV Market Share) and a word on Tesla later.

Figure 3: Electric and Plug-in vehicle stock. Source: IEA Global EV Outlook, Apr 2024.



Sources: Link in Links and Resources below

Figure 4: EV sales, SNE Research



In Europe, new electric car registrations reached over 3 million in 2023, marking a substantial increase of almost 20% compared to 2022. ***European governments have historically offered some of the world's most "generous incentives" funded by taxpayers for the purchase of new EVs.*** However, these subsidies are beginning to wind down, notably in France, where a EUR 7.000 (assume 1,1 USD per 1 EUR for simple conversion) per vehicle bonus is set to drop to EUR 4.000 in 2024 and Germany bringing its EUR 4.500 subsidy for the purchase of a new EV to an end. (IEA World Energy Investment 2024, p144-146).

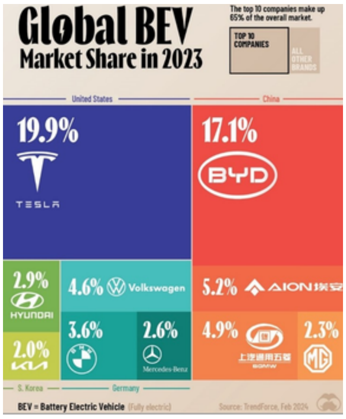
Surprise, surprise, without any delay, the first "worrying" headlines started to appear:

- **Die Welt:** In the 1st half of 2024, Germany's EV sales are down over 40%, plug-in hybrids over 30% down, while diesel and gasoline cars grew over 20% (Figure 6: Germany H1 2024 EV sales)
- **The Times:** The electric car crash will rival the dotcom bubble (May 2024 – Link in Links and Resources below)

While most surveys published appear to be pro EV, the McKinsey 2024 Consumer Survey uncovered that 29% of electric vehicle owners consider to switch back to a traditional combustion engine car (Link in Links and Resources below) . This is an interesting unpopular surprise to many?

So far it remains a fact that EVs are usually bought as a 2nd, third, or even fourth car by more affluent people (Figure 7: Who buys EVs). Consider Germany or North America, who drives EVs and do they have a combustion engine car in the garage as well? Who lives in the city or who are homeowners with a charging station?

Figure 5: EV Market Share. Visual Capitalist, Mar 2024



Sources: Link in Links and Resources below

Figure 6: Germany H1 2024 EV sales

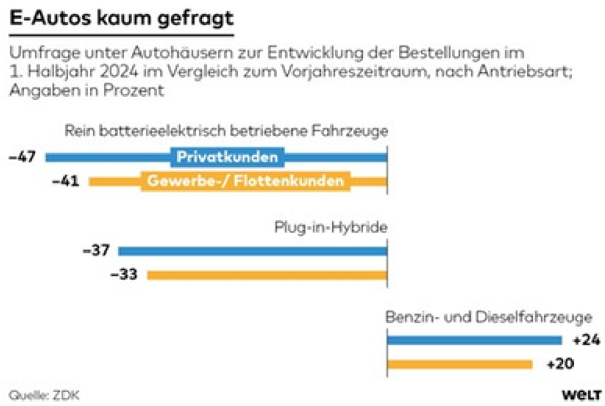


Figure 6: Germany H1 2024 EV sales. Source: Welt – Link in Links and Resources below

1.3 Car companies, EV and non-EV

What is interesting to see is how EV companies are faring out in the market. How difficult is it to build an EV manufacturer? In theory, we all can "invent" a new EV brand and start an EV company within 2-3 years with the 5 following key elements

1. Sufficient funds from "willing" investors
2. A good designer and marketing team
3. An electric motor
4. A decent battery that is not too expensive
5. A computer and some experienced programmers

There is even a whole website on it 😉 Launching your Electric vehicle startup – FasterCapital (Link in Links and Resources below)

Of course, there is more to it, but you get the point… the barriers to entry to build a business are much lower for an EV car than for a standard combustion engine car, which has a higher degree of mechanical complexity.

While some of us more technically minded people may love mechanical mastery, such complexity is not required for every business and often not wanted by customers. What is relevant here is the fact that the low barriers to entry for EVs basically mean business margins will also be lower on average… or even negative?

EV startup companies such as Rivian, Lordstown, Lucid, Vinfast, Polestar, Canoo, Fisker tell the stories about losing billions of dollars of investor money fast! (see the post about the article at WSJ 2024 in the references).

In addition to the low barriers to entry there are concerns about costs and of course the service that EVs provide compared to standard cars.

I do not doubt and fully agree that there absolutely is a market for electric cars for instance in dense city centers for fixed routine work or the golf course (oh wait, they are already working there). What I am trying to say is that many EVs have a utility to customers that makes a lot of sense… the problem is the completely unrealistic and undesirable attempt to replace practically 1+ billion vehicles globally with EVs. Please consider the impact such a venture has on our power grids and the mining, refining, and disposal industries (see Part 2 of this series).

Figure 7: Who buys EVs, Schernikau based on Gallup 2023

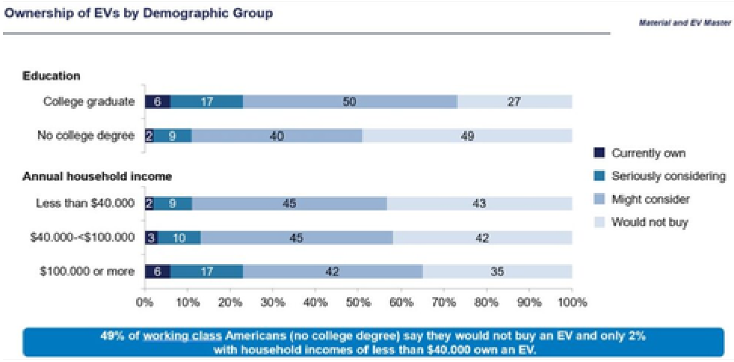


Figure 7: Who buys EVs, Schernikau based on Gallup 2023

While the standard car industry has faced many difficult years, overall it has been quite profitable with leading manufacturers reaping billions of USD annually, with Ferrari and Porsche having the highest profit margins. Details at good car bad car, Which Automaker Was Actually The Most Profitable In 2023? (Link in Links and Resources below). We will talk about Tesla shortly. The same can unfortunately not be said for EV companies. (Links in Links and Resources below)

While in 2021 many companies announced “we will stop producing gasoline cars” (NYT Nov 2021 – Link in Links and Resources below), recently, more and more companies are back paddling.

A word on Tesla. The company is highly profitable and one of the most valued companies globally (Market Cap beg Aug 2024 was $775 Bln USD). However, the company has been receiving large subsidies and makes a lot of money from selling its “Zero-CO2” allowances to other companies. This is an interesting business model and masks the real profitability of its sold EVs, or maybe better the lack of such profitability.

You can read some details here:

- “Tesla’s brand new plants in Germany and Texas will eventually help the electric-car maker dramatically boost output but for now they’re “money furnaces” losing billions of dollars, according to CEO Elon Musk.” (Forbes, Jun 2022 – link in Links and Resources below)
- “Tesla to Get US$41 Billion in Government Subsidies over Made-in-US EVs and Batteries.” (Notebookcheck, Jun 2023 – Link in Links and Resources below)
- “Tesla Reveals Profit Bump From Government Credits After SEC Push” (Bloomberg, Mar 23 – Link in Links and Resources below)

1.4 CO2 footprint of EVs versus combustion engines?

When comparing the environmental impact of combustion cars with EVs, ***usually the life-cycle CO2 emissions are compared. This is of course logically wrong,*** as if CO2, a greenhouse gas with diminishing warming impact, but also the basis for all life on earth, is the only and true measure to environmental sustainability.

There is so much more to environmental “sustainability” and I covered this subject in my recent article **“The Dilemma of Pricing CO2”**. Things to consider include what I will also cover in part 2 of this series.

- Raw material impact
- Disposal impact
- Manufacturing impact
- Electricity supply
- Human and Animal safety, particle emissions from weight increase, explosion and fire risk
- And more

But even when CO2 is counted, there appears to be a lot of uncertainty, just one example is Volvo that in 2021 already said that ***“emissions from making EVs can be 70% higher than petrol models”*** (they mean CO2 of course, emphasis on “can be”).

Obviously, such a statement has a lot of assumptions on how and where the car was built and how and where the battery is charged with which electricity source.

But I can promise you that there is not one single “Zero CO2” EV running in the world today. Clearly EVs are wrongly taxed and accounted for as “Zero-CO2” in countries’ and companies’ “Net-Zero Pathway” plans. Using the coal-fired grids of Poland or South Africa to charge your EV, you would have to drive over 1 Mln km to come to CO2 parity… or would you ever? See Michael Sura’s article (Link in Links and Resources below) and numbers for Poland.

There are countless analyses that confirm that if the goal is to reduce CO2 emissions from passenger caros, EVs are NOT a solution.

I will not try to recreate these analyses here. But applying a more comprehensive and realistic life-cycle view and durational lifetime of batteries, I conclude that you may drive on average 150.000 to 200.000km with an EV if you are lucky?

“Lamborghini Doesn’t Think Electric Supercars Will Catch On.” **Motor 1, Jun 2024.**

“Porsche Drops EV Target Over Cooling Demand, China Slowdown”, **Bloomberg, Jul 2024**

“Mercedes-Benz Delays Electrification Goal, Beefs up Combustion Engine Line-up”, **Reuters, Feb 2024**

“Volvo, An Early Electric Car Adopter, Cuts Off Funding For Its EV Affiliate”, **WSJ, Feb 2024**

“BMW Boss: Oliver Zipse with doubts about European EV strategy,” **Handelsblatt, Sep 2023**

“VW Will Spend Billions on Gas Engines.”, **Motor 1, Jun 2024**

“GM Is Investing Almost $1 Billion in New V8 Engines,” **JalOpnik, Jan 2023**

Well, have a look at some of the reports below including the mentioned sources which will give you a glimpse of the issues and how illogical it appears to assume that EVs will substantially reduce global CO2 emissions or will make a positive difference to the environment. (Links in Links and Resources below)

- "Electric Vehicles Emit More CO2, Not Less", Covexit, Covexit Feb 2023
- Neugebauer et al 2022: "Cumulative Emissions of CO2 for Electric and Combustion Cars: A Case Study on Specific Models." Energies, 15, Jan 2022
- Profs Koch & Boehlke 2021: "The Averaging Bias – A Standard Miscalculation, Which Extensively Underestimates Real CO2 Emissions" (summarized at Auto Motor Sport 2021, and Focus 2021)

Let me repeat, I do believe that EVs have a role to play in the future of mobility, but this belief is not driven by CO2 efficiency.

How it is driven, I will discuss in Part 2 of this series.

1.5 Summary Part 1

In Part 1 on EVs I covered the history and current market of EVs. 30 Mln fully electric vehicles on the market globally today, make up less than 3% of the global vehicle market. New electric vehicle sales are already exceeding 15%, but "EV growth bumps" are starting to appear.Chinese manufacturers are taking over the market fast. They are growing while western auto manufacturers are stumbling. Government subsidies and support for EVs, battery and charging infrastructure amount to billions. But the sentiment in Europe and North America is changing, with subsidies slowly drying up. Germany's slump in EV sales in the first half of 2024 is evidential of this.

EV auto manufacturers around the globe are in trouble it seems. Incumbent companies losing billions of dollars and startups burning through their cash. There are many reasons for this which we will explore in the 2nd part on EVs.

Interesting is that the life-cycle analysis of EVs and combustion vehicles is not as favorable as often portrayed. Don't forget that everyone is literally only counting CO2, not the true environmental footprint along the entire value chain which goes far beyond CO2… which is a grave mistake as I pointed out here **"The Dilemma of Pricing CO2".**

Let me repeat, ***I am of the honest opinion that EVs have a place in the market.*** They are beneficial to the consumer under certain circumstances (other than accelerating "ludicrously" fast). It is up to the consumer to choose what makes sense for her or him.

I hope I piqued your interest to read the 2nd part on EVs where I will be focusing on the impact of EVs on power systems and supply chains plus exploring the future. We will also review some of those safety hazards of EVs, which are more substantial than I thought before I started researching for this article.

2. Part 2: EVs' impact on power systems and supply chains

Today, there are 30 Mln fully electric vehicles on the market globally, which makes up less than 3% of the vehicle market. New electric vehicle sales are already more than 15%, but "EV growth speed bumps" are starting to appear.

Did you know, ***"Electrified Transport" is the single biggest investment*** envisioned for achieving "NetZero"? In May 2024, Bloomberg New Energy Finance BNEF reported that ***we need to invest on average an annual $ 4.4 Tln, or cumulatively $ 120 Tln, in EVs from 2024 through to 2050, in order to reach "NetZero"!*** (Link in Links and Resources below) No wonder this is a "popular" industry to be in… definitely worth to explore how to get a piece of that pie, don't you think?

Here I will not cover the incorrect "net zero" assumptions that BNEF and others make about EVs, which will be quite obvious to you once you reach the end of this article. As per BNEF "electrified transport", already received $600 Bln investment in 2023 alone, so to reach goals, this number "only" needs to multiply 8x on average for the next two and half decades (Figure II-1: Energy Transition Investments).

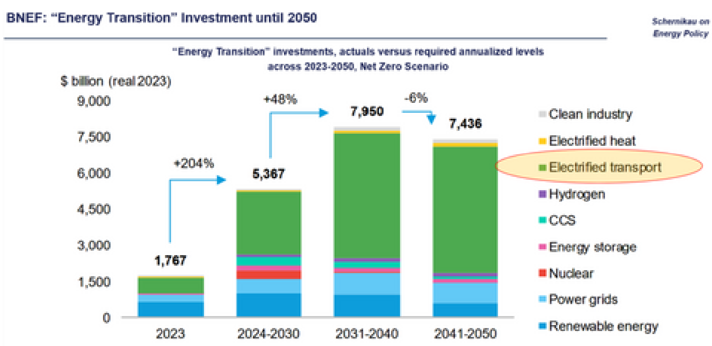
Part 2 focuses on the supply chain of EVs and their impact on our power systems.

Electric motors always had a much wider use case than transportation. In fact, electric vehicles (EVs) appeared rather secondary. Electric motors were used for an array of industrial and consumer applications, but always requiring an external power source, connected by a wire (see modern trains). The idea to completely "electrify" transport comes from the wish to replace oil-based CO2 emitting fuels with "zero CO2" electricity to "save the environment" (which I assume "the climate" is part of).

Chinese manufacturers, in order of importance BYD, SAIC, Seres, Li-Auto, Chery, GAC Aion, Great Wall Auto, Zeekr, Nio and more, are taking over the market fast. They are growing while western auto manufacturers appear to be stumbling.

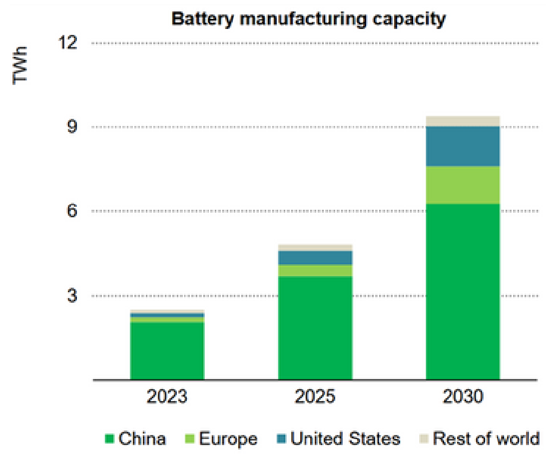
Although government subsidies and support for EVs, battery and charging infrastructure amount to billions, the sentiment in Europe and North America is changing, with subsidies slowly drying up. Germany's slump in EV sales in the first half of 2024 is evidential of this. EV auto manufacturers around the globe are in trouble it seems.

Figure II-1: Energy Transition Investments



Source: BNEF NEO 2024 Link in Links and Resources below)

Figure II-2: Battery manufacturing capacity



Source: IEA World Energy Investment 2024, p148, based on Benchmark and Bloomberg (Link in Links and Resources below)

Taking a step back, let`s consider the conversion process within the vehicle (fuel to motion, vs electricity to motion) ***We can agree that EVs are much more efficient, but what happens before the conversion process***, is largely about battery manufacturing. Battery "making" is expected to reach 9 TWh output annually within the next 6 years, or the equivalent output of 180 Tesla Gigafactories producing 50 GWh every year.

What does this really mean for the environment we are aiming to protect? Let's have a look

2.1 Raw material and energy input

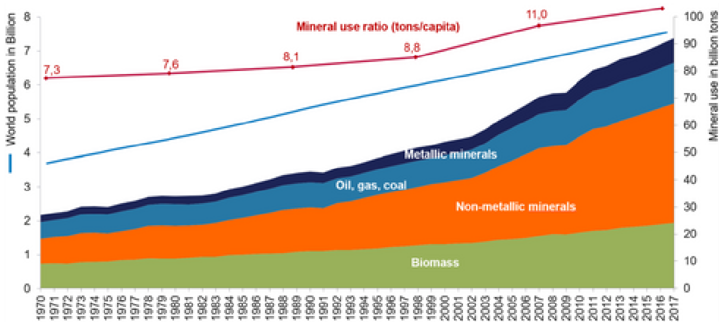
The raw material efficiency of cars is a key environmental consideration. Humanity's goal should be to become more material and energy efficient in all our endeavors. That, by the way, does not mean we will use less energy or raw materials, but rather aiming for higher efficiency, meaning we will be increasing utility thereof. ***Everything we produce and consume ultimately originates from "raw" materials,*** and so do electric and non-electric vehicles. So what is the problem then?

Figure II-3 illustrates that for its existence, humanity today requires almost 100 Bln tons of grown and mined minerals. The material consumption per capita has been continuously increasing, which has been largely driven by the reduction of poverty. ***Classic fossil energy raw materials contributing to over 80% of global primary energy make up only ~15% of all minerals extracted.***

When we speak of material input, we often consider steel, copper, cement, glass, aluminum, or silicon as base products as a direct input. However, as mentioned above, these materials must first be mined, produced and upgraded, requiring energy, from mined raw materials such as iron ore, coal, limestone, silicon, bauxite, quartz stone, etc.

Now getting back to EV batteries, which typically account for 30% to 40% of the value of an electric vehicles. Those batteries require input consisting of lots of non-metallic and metallic minerals… ***A 85 kWh battery for a Tesla, which is rather large and weighs about half a ton adjusting for the average ore grade (1-2%), requires about 25-50 tons of raw minerals*** to be mined, before the processing & transport chain can start. Is this considered as all green and "net-zero"? I have my justified doubts.

Figure II-3: Global mineral extractions



Sources: Schernikau/Smith Book, Chapter 2.6 "Unpopular Truth … about Electricity and the Future of Energy", Graph can be downloaded here

These minerals, depending on the battery type, usually make up the bulk of production (estimated in order of importance by Visual Capitalist 2022, Figure II-4)

- Graphite
- Aluminum
- Nickel
- Copper
- Steel
- Manganese
- Cobalt
- Lithium
- And steel (iron)

The costs of a metal in both dollar and environmental terms are dictated primarily by ore grades, i.e., the share of the rock dug up that contains the metal sought. Also, related is the depth of the ore and thus the quantity of "overburden"- the rocks, dirt, trees, etc., on top of that the ore - that must first be removed.

Iron is a uniquely abundant metal in iron ore; not so the suite of critical "energy minerals," for which ore grades range from 2% to 0.1%. Average nickel ore grade is under 2% and for copper below 1%, which means, arithmetically, that at least 1 ton of metal requires the discussed 25-50 tons of rock, excluding the overburden. Such geological realities determine the amount of energy used by big machines to do the digging, moving, grinding, transporting, refining, etc. (Mark Mills 2024, Link in Links and Resources below)

- ***assuming an 1:10 average overburden ratio, the tonnage to be moved would reach 250-500 tons for each Tesla Battery***

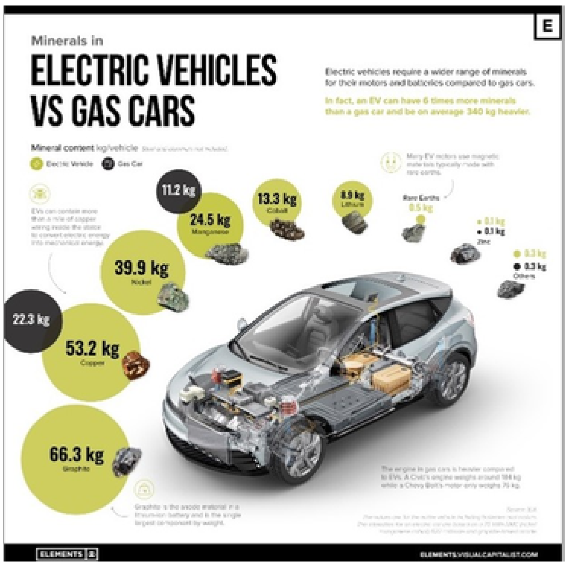
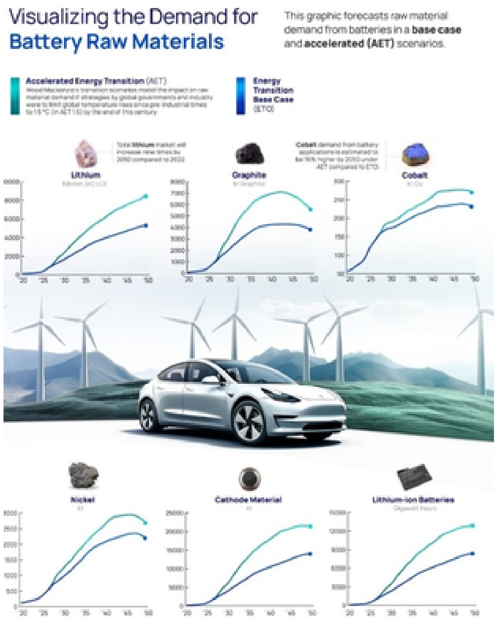


Figure II- 4: Demand for Battery Raw Materials



Sources: Visual Capitalist 2023 based on Wood MacKenzie and IEA (Link in Links and Resources below)

In addition to the raw material tonnage you require significant amounts of energy in the form of heat and electricity for mining the materials and to manufacture the batteries. This energy is often called "embodied" energy of a product or material. For instance, aluminum has about 170,000 MJ per ton of embodied energy, while copper "only" has 60,000 MJ/t.

I suspect these amounts do NOT truly include all energy required, but I speak under correction. The acclaimed book *Sustainable Materials without the Hot Air* by Cambridge researchers Allwood and Cullen 2015 summarizes the concept of embodied energy very well.

We understand that China dominates the entire value chain for batteries and most mineral processing (Figure II-5), and ***we know how China provides the heat and electricity required for this process, which is largely with coal!***

- Let us please also not forget that the chemical element carbon (from coal) is often required for chemical reduction (not just for heat or electricity). For instance, steel is an alloy of iron and carbon; it can also contain small quantities of silicon, phosphorus, sulfur, and oxygen.
- Each ton of steel requires ~1,6 tons of iron ore, ~800 kg of coal, and products such as limestone and various additives; let us approximate the total to ~2,5 tons of input raw materials for each ton of steel.
- Therefore, the ~2 billion tons of steel produced in 2022 required approximately 5 billion tons of raw materials which were extracted, transported, and processed. Thus, steel production appears to consume a little more than 5% of all global raw materials (from our book ***"The Unpopular Truth… about Electricity and the Future of Energy,*** Chapter 2.6).
- Oh, Silicon for solar panels also **always require coal** as a reductant.

Today, ***mining worldwide accounts for about 40% of global industrial energy*** use and over 10% of global final energy consumption. Diesel, or refined oil products, accounts for half of the mining-sector's energy use. (Guilbaud 2016, Mark Mills 2023, Links in Links and Resources below)

The fact that ***EVs are much more material intensive than standard vehicles*** is not disputed and has been confirmed by the IEA multiple times. I trust I don't have to "prove" this here (Figure 4). Another logical point is that the larger the battery and bigger your vehicle (i.e. a bus or truck), or the longer the distance you travel, the more disadvantaged EVs are, when it comes to the raw material and energy "backpack" it carries, even before you turn it on the first time, in comparison to standard cars.

The idea is of course that once the car is built it emits "zero CO2" and makes up quickly for that "backpack", which we will cover in the next section. The problem I see when equating CO2 efficiency with environmental protection, is covered in my article **"The Dilemma of pricing CO2".**

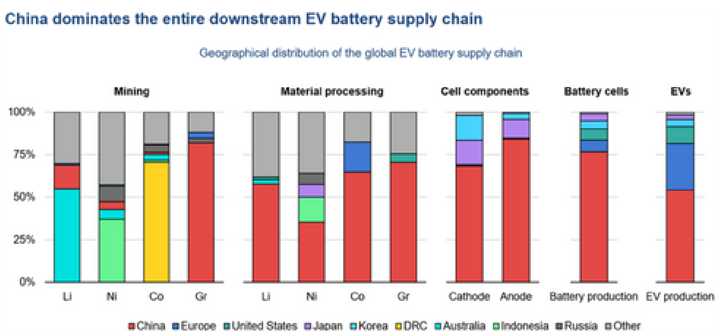
Now, let's ask who will produce all these raw materials? This is an interesting question with serious environmental consequences. The renowned energy economist Mark Mills 2024 pointed the following out "IEA says that will require hundreds of new mines. Benchmark Mineral Intelligence puts the number at 384 new mines just to meet EV needs for the graphite, lithium, nickel, and cobalt [that] will be required to meet EV demand by 2035." (Link in Links and Resources below)

- Wood MacKenzie (Figure II-4) estimated production increase of 6 "critical minerals" based on a much lower battery demand case of 8 TWh by 2050 than the IEA in Figure 2 with over 8 TWh by 2030…
- Prof Simon Michaux (Michaux 2024) has done advanced calculations with more realistic assumptions calculating that a largely electric vehicle fleet would require over 60 TWh of battery capacity for just "one generation", as these batteries don't last long.
- **Schernikau/Smith 2021** calculated a theoretical solar-only powered Germany would require 2,25 TWh of batteries every single year (45 TWh total) for 14-day storage only, translating to over 5x global lithium production and over 20x global graphite anode production.

It seems like recycling and the "green circular economy" remain a distant dream. The IEA positively estimates that 1-2% of battery demand could come from "recycled minerals" (IEA 2022, Mark Mills 2023). But since batteries are, unrealistically, expected to last 10 years on average, recycling cannot play any significant role until mid 2030.

To date, the "circular economy" consists of: ***(1) mining in Africa, (2) processing and manufacturing in China, (3) shipping to Europe and North America for a few years of usage, then (4) shipping the waste back to Africa*** for landfills.

Figure II-5: China dominates EVs



Sources: IEA 2022 based on Benchmark, US Geological Survey, BNEF, others

I have seen some of those landfills filled with European electronic waste in Africa with my own eyes (see also Deutsche Welle 2022, link in Links and Resources below)

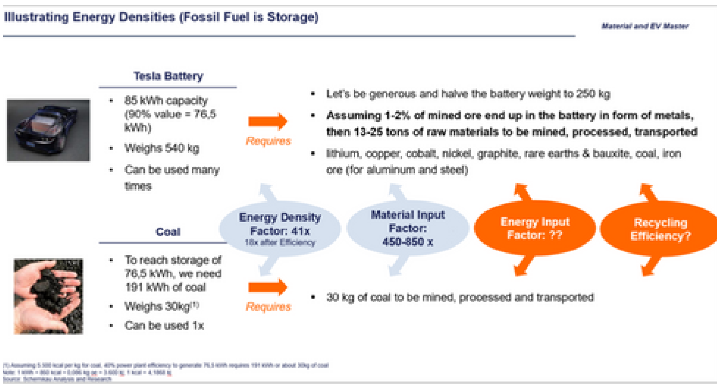
In summary, evaluating the raw material requirements for the "EV Revolution" is such a tremendous task that only a few have truly mastered it. The IEA touches on some of those challenges in their reports but continuously underestimates the task. By the way, did you know the ***European Union classifies Coking Coal as a "critical mineral", yet has stopped support for ALL coal projects*** in Poland and worldwide?

A recent IEA Tweet from Apr 2023 reads: *"The scaling up of clean energy technologies will drive huge demand for the minerals & metals used to produce them."* Another IEA Tweet 2024 correctly states *"The clean energy system requires more mineral resources than an energy system based on fossil fuels".*

If you want to better understand the challenges faced because of the raw materials required for the "EV revolution" you may also want to look at Mark Mills 2024 and watch his highly recommended and celebrated 45min video "The energy transition delusion: inescapable mineral realities" (Link in Links and Resources below)

I also recommend listening to or reading Prof Simon Michaux's work (Michaux 2024). In his presented at the European Union he estimated that, if Europe was going 30% "non-fossil" by 2023, it would need 80 Mln EVs with 11 TWh of batteries and a few other things. If one assumes a 28-day buffer, Europe alone, by 2030 (6 years) will require 280 years of current annual production of lithium.

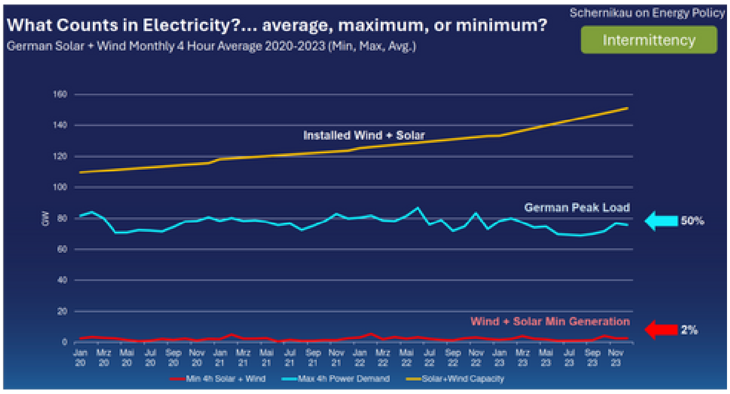
Figure II-6: Energy density of batteries and coal



Sources: Schernikau/Smith Book, Chapter 2.6 "Unpopular Truth … about Electricity and the Future of Energy", Graph can be downloaded here

2.2 Sources of power

Figure II-7: Worst 4h Wind and Solar period each month in Germany



Sources: Schernikau, based on Agora actual data

We now understand what it takes to "just" build batteries. However, remember that those batteries are not yet charged for use. Because of their low energy density (kWh per kg), they require a lot of upfront investments in the form of raw materials and energy and ***these "heavy energy storage units" need to be carried around all the time*** (Figure II-6: Energy density of batteries and coal).

How will we charge these batteries? The electricity required for charging will come from the grid. If you are very affluent, have your own power source (solar?) and storage to get through days or weeks of no sun or wind (batteries and hydrogen?) you could potentially be independent and completely off the grid. But I have yet to see a small town in Europe or the US that is truly off the grid.

Only if you had to truly and entirely be disconnected from the grid at all times, would the utility NOT have to consider your EV's power demand. The fact remains that on average you will depend on the grid as the source of power or at least a backup for the worst-case scenario. My own analysis illustrates that every single month there is practically no wind and solar in Germany during the worst 4h periods (Figure II-7).

That EV's can be charged from your rooftop solar panels is a novel idea and may be possible during sunshine hours. But thinking your EV battery can act as storage for "dark" hours means you can't drive the day after it was "dark". And of course, the idea of using EV batteries as grid storage is a completely unrealistic notion.

How much power do large amounts of EVs need?

How much power would you then require? Let's revert to a theoretical case – ***if 60 Mln German vehicles were all electric, each running on a 60 kWh battery.***

The short answer: peak power demand in Germany would double from 80+ GW to 160+ GW.

The slightly longer answer would be – if we wanted to charge all 60 Mln cars throughout the year, considering wintertime with very little solar power potential and sometimes very little wind for extended periods. Here five assumptions:

- Weekly charge required is 40 kWh (about 200km per week, or 10.000km p.a.), about 125 TWh p.a. (40k Wh x 60 Mln x 52 weeks)

- Battery weighs 5 kg per 1 kWh (500kg for a Tesla 100 kWh battery)
- Average 2% ore metal ratio in batteries… meaning average copper ore, lithium ore, nickel ore, bauxite ore, cobalt ore, etc… 2% content in mined ore (of course it varies very widely from 0,05 to may be 20%)
- Average charger used 50 kW (Tesla's fast chargers reach 100 kW or even 250 kW, see V3 and V4
- One Tesla Gigafactory manages to produce 50 GWh batteries p.a. (Tesla Berlin has plans to double to 100 GWh)

For the calculation, the charging pattern is key: One week has 168 hours, so on average 357.000 cars per hour (60 Mln / 168h) to be exact a 40 kWh charge takes 48 min with a 50 kW charger.

- 60 Mln cars with 60 kWh batteries = 3,6 TWh battery capacity in total, to be replaced every 10 years, thus 360 GWh new batteries each year
- That means it would take 72 Gigafactories 1 year to produce this or 7 factories would work constantly, all year-round to produce batteries continuously for Germany alone
- Batteries would weigh 18 Mln tons
- ***About 1 Bln tons raw materials would have to be mined, transported, processed, upgraded, etc, or about 100 Mln tons each year if the cars are replaced every 10 years (with no growth and negligible recycling)***
- at an overburden ratio of 10:1 this would mean 10 Bln tons of overburden to move to get to the ore
- 40 kWh charge per week if spaced perfectly, would mean 357.000 cars charge with a 50 kW charger = 18 GW peak power…
- But more realistically perfectly spaced is impossible, and assuming only 5x inefficiency, then 1,8 Mln cars (which equates to 3% of the fleet) could charge at same time translating to about 90 GW peak power demand… and the grid has to be ready for that.

In the most positive scenario, it would mean that Germany's peak power demand would double from currently 80+ GW to 160+ GW. Remember that wind and solar are NOT peak power capable without effective energy storage… only coal, gas, hydro, biomass and nuclear are. Also remember that we have NOT yet considered the electricity demand of those 7 Gigafactories running around the clock, nor the charging infrastructure, power lines and more… all requiring energy and raw materials, that still need to be built.

The increasing power demand from EVs was summarized by Bloomberg 2023 "*Electric Vehicle Boom May Force China to Burn More Dirty Coal*". (Link in Links and Resources below) There is no doubt that EVs already increase peak power and total power use everywhere in the world! But what does that mean for the grid mix, why is Bloomberg saying this about coal?

Here is an important point made by various energy economists respectively: it can be assumed that ***the additional power required for EVs (or AI) will be less "green" than the average power in the grid.*** Follow this logic …and let me know if I am mistaken.

- We are already doing everything possible to install as much wind and solar, with or without additional EVs. We should assume we cannot do more. The average grid power over a year thus has X% wind and solar (in Germany about 40% in 2023, after 33% in 2022), and a small fraction of curtailed unused wind and solar Y%.
- Additional demand from1 Mln EVs (approx. 1,3 GW peak power, 2 TWh p.a.) will now have to come from somewhere… and that being a) curtailed wind and solar or b) from none-wind and solar, conventional power supply, also at times and wind and solar contribute practically zero (Figure II-7).
- If (1) and (2) are correct, and Y% is far less than X, then logically the additional demand from EVs will reduce the average % of wind and solar in the system and increase "emissions".
- Koch and Boehle 2021 wrote a peer-reviewed paper on this subject (Link in Links and Resources below)

That a larger power system also has other implications for the environment and the total cost of the power system should be clear by now. More trees for utility-poles (see Wallstreet Journal article "*The Electric-Car Era Needs a Lot of Really Big Trees*", WSJ 2023), additional "power plants", more complex distribution systems, disposal and waste issues, just to name a few.

Germany's investment of over $6 billion in EV charging infrastructure shows a crucial step towards accommodating the electric vehicle influx, but does this make environment and economical sense? Who is footing the bill and where will the raw materials and energy come from to build these chargers? What is the "asset utilization", who maintains them where are the chargers disposed of after their useful life? On and on the questions go. We understand that even the most pro-active scenarios mean that ICE and EV will live side by side for many decades, leading to duplication of infrastructure (existing gas stations and new charging infrastructure).

- The fact is that charging stations are, economically much more problematic. You fuel your car in 5 minutes but to charge an EV fully can take hours (depending on the charging power) thus, reducing serviced customers per day, leading to a need for a multiple of charging stations to "replace" the utility of one single nozzle at a gas station.

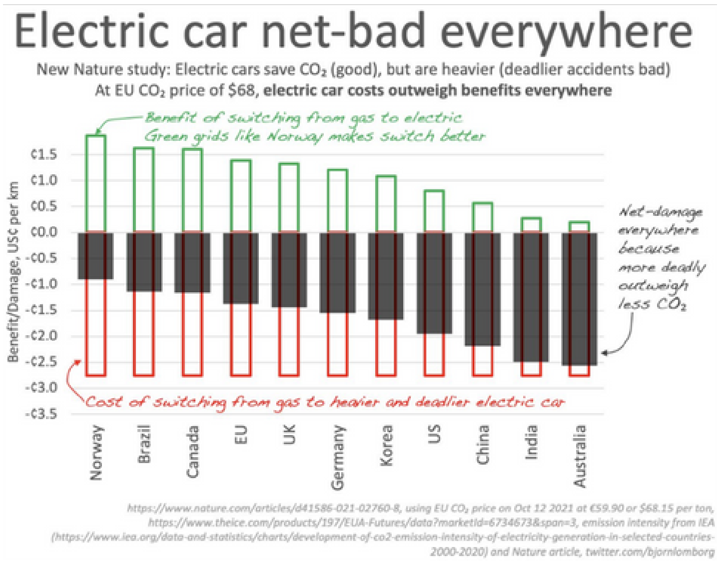
When it comes to charging, the issues are (1) where and how the electricity is produced and (2) how the electricity gets to the electric engines. Today's trains run on rail with overhead connections to the powerplant (usually coal, gas, or nuclear) that is overall quite efficient. An EV on the road however, is supposed to use only "green" electricity from wind, solar and hydrogen and then use a battery to store this energy for future use? I hope you see why this is an unrealistic hope.

For that reason, EVs are not truly as "green" as they are usually portrayed. I would like to reiterate, that I am in support of electric vehicles where the consumer choses and where it makes a difference to divert emissions from city centres to rural areas globally. I simply question the global environmental and economic logic of forcing users from combustion to electric vehicles, not even touching on the "climate benefit".

2.3. Safety concerns

There are three main risks to consider with a larger adoption of electric cars: 1) increased risk from heavier cars 2) increased explosion risk of batteries 3) significant performance decrease in high or low temperatures, i.e. when it snows, it increases safety risks.

Figure II-8: electric cars are "net-bad" everywhere



The safety of current battery technology is a serious concern illustrated by a Chinese man (in July 2024) who carried his portable e-bike battery into an elevator, which subsequently lead to a deadly explosion in the closed elevator (see short *not-kid-friendly* video "eBike China 2024" under references). While this is an unusual and tragic event, it illustrates the seriousness of the explosion hazard posed. (Link in Links and Resources below)

We all hope the issue will be solved in the years and decades to come, but right now it remains a grave problem.

The list of issues with batteries is long. Travelling in Vietnam recently, I spoke to many a scooter drivers who told me anecdotes of how e-scooter users are switching back to fuel-based scooters simply because of so many examples of bikes igniting and exploding in homes. In Vietnam it is not unusual to park your motorbike in your living room overnight. We are all aware of how difficult it is to extinguish battery fires, hence airlines not allowing even a small 5.000 mAH battery pack to be carried in your check-in luggage.

Did you ever wonder why?

Battery powered cars are also deadlier because of their weight, a simple fact of life. Heavier, vehicles, by the way, has been proven to cause more particle pollution from tire abrasion. Dr. Bjorn Lomborg has summarized the trade-off in a simple graph. However, he was also not able to consider the true environmental impact of EVs, leading to positively exaggerated numbers (Figure II-8).

A cherry-picked incomplete list of global responses to safety risk from batteries:

- National Transport Safety Board: Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles (NTSB 2020)
- Insurer stops insuring EVs: John Lewis Stops Insuring Electric Cars over Repair Cost Fears (JohnLewis 2023)
- Extreme fire risk with EV´s exposed to salt water – Coast Guard issues alert to not allow on ships; CTIF – International Association of Fire Services for Safer Citizens through Skilled Firefighters (CTIF 2022)
- Germany, first city closes parking houses for EVs because of fire risk (Focus 2021)

It appears that electric car will NOT catch fire more frequently than standard cars (adjusted for driven km), but the severity of a fire is significantly worse, basically battery fires can hardly be extinguished. Countless stories globally illustrate this point. A simple google search will reveal more.

- eBike combusted in elevator in China, kills man, July 2024, (eBike China 2024)
- Tesla top-of-range car caught fire while owner was driving, lawyer says (Reuters 2021, Figure II-9)
- A Lithium-Ion Battery Fire in a Cargo Ship's Hold Is out after Several Days of Burning, Jan 2024 (AP News 2024)
- Massive Tesla Battery on Fire at Renewable Energy Plant in Australia, Jul 2021 (CNET 2021)

There are also risks associated with dead batteries leading to vehicles not being responsive

- Woman trapped in Tesla after Battery died (KKTV 2024)
- Numerous Tesla owners report being trapped (Yahoo 2024)
- Chicago shows Teslas struggle in cold weather. Here's why (Quartz 2024)

Battery Dies in Cold Weather: Why? Renogy 2024 explains why battery cells are sensitive to environmental conditions. When the temperature drops significantly, it can cause serious damage to your batteries. But why do batteries die in the cold? When the temperature drops, the chemical reactions required to generate energy become slower and less efficient. This prolonged stress causes a degradation in capacity and discharge rate of the battery. Additionally, the battery becomes less mechanically stable, increasing the possibility of a sudden failure. Unfortunately, any temperature lower than 0 °C can cause appreciable damage to the batteries.

There is no surprise that Tesla had to "hide" battery issues and complaints for years (Reuters 2023), and that its range on average is far lower than stated.

The ***disposal of batteries*** is not discussed in more detail. But Science Magazine 2021 had a good short article *"Millions of electric cars are coming. What happens to all the dead batteries?".* You can imagine the conclusion "Recycling researchers, meanwhile, say effective battery recycling will require more than just technological advances. The high cost of transporting combustible items long distances or across borders can discourage recycling". In the meantime, ***we just dump those highly toxic batteries in Africa.***

Figure II-9: Tesla car caught fire while owner was driving

2.4 Summary Part 2

Again, ***I fully agree that there is a market for electric vehicles*** for instance in dense city centers, fixed routine work or the golf course.

- Yes, the electric engine, in itself, is more energy efficient than the internal combustion engine, but I strongly feel that we need to consider the ***entire supply chain from production to charging requirements, consumption, and then disposing of these toxic materials.***
- The poor resale value and short lifespan of an EV, ***driven by the fast deterioration of the valuable battery,*** just creates another serious situation for the consumer to consider when it comes to buying an EV (TKP 2023).
- Even if, low energy dense batteries, were to double in energy efficiency, ***the peak power demand requirements make the widespread use of EVs in larger populated countries, completely unrealistic.*** It is, from an economical view, laughable to consider electric trucks, planes, and boats!

I vehemently protest government intervention in the choice for EVs vs ICE which largely has do to with the many environmental and economic issues which arise with a wider adoption of electric cars. For instance, a ***CO2 taxation of zero for EVs is as "ludicrous", as the speed of a Tesla.*** The misinformation (nicely put) must be exposed, as only by shedding light on the situation and creating understanding, we will bring about positive change.

These proposed solutions merely divert emissions to other areas. We should be measuring all the safety hazards and also considering the total environmental and economic impact, which is clearly not positive at global scale.

There is so much still to be done, including a true-life cycle analysis of EVs and ICE at a scale that includes the ***entire supply and value chain from production to disposal.***

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