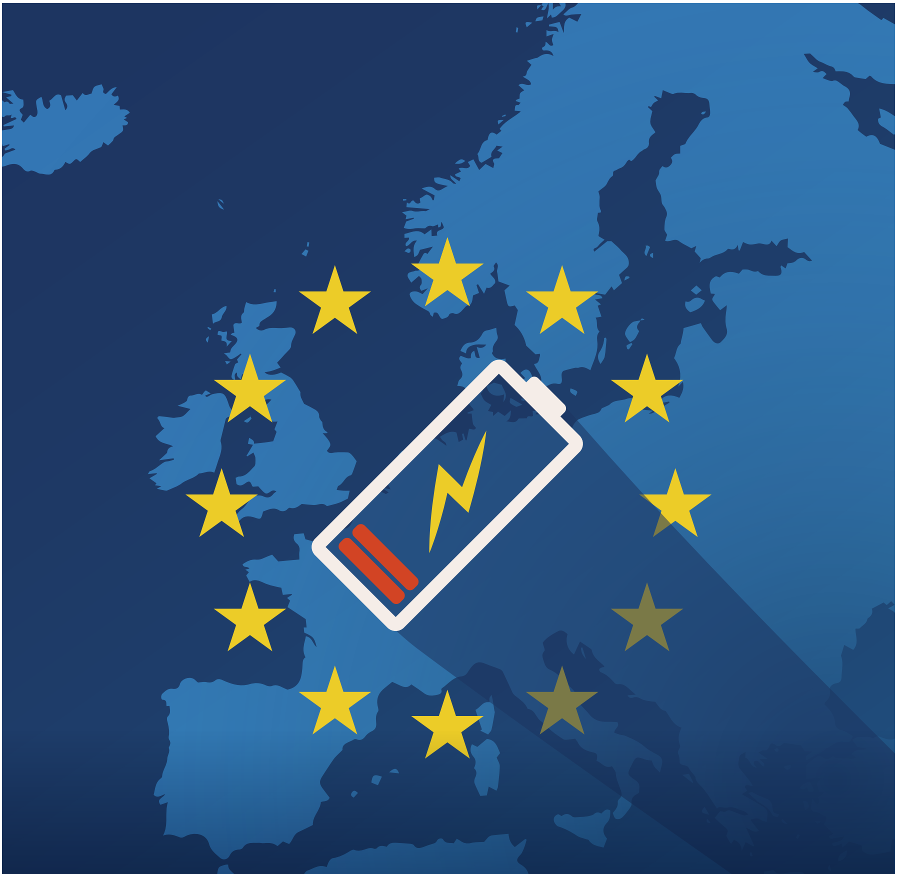

Behind the Batteries: The Hidden Cost of Green Mobility

Edited by
Tamás Jakab, Anna Vindics

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INDÍTSUK BE MAGYARORSZÁGOT

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Energy supply is an existential issue

Europe's dependence on Russian gas has been one of Putin's most powerful weapons in the brutal war against Ukraine. And Russia is far from alone playing this game. Rogue states that nurture the world's dependence on fossil fuels gain leverage for blackmail as well as significant sources of income. Right now, China is building a pipeline to pump oil in Africa.

There is no doubt that a transition away from fossil fuels is absolutely central for the climate and for the fight against dictatorships. One of the most crucial measures to enable this transition is electrification. Industry and transport must adapt.

Access to climate-smart batteries is the key to ensuring that this necessary electrification is sustainable all the way through. With batteries, everything from small household appliances to large vehicles and massive industries can break their dependence on fossil fuels. In the previous mandate I negotiated the EU's new Battery Regulation. A new model for environmental legislation follows the battery through every phase: production, consumption, and recycling. Every step in the process must meet sustainability standards and guarantee that batteries in Europe are indeed the best in the world; while ensuring we do not create new harmful dependencies.

The legislative framework creates a circular market by requiring that new batteries contain a certain amount of recycled material. To ensure that battery use and production in Europe does not come at the expense of the environment or prosperity in other countries, batteries on the European market must be subject to so-called "due diligence" rules. These will safeguard human rights and environmental protection throughout the value chain.

The green transition is not a highway towards sustainability if we ignore the sometimes complex environmental consequences of battery production. We have to be ready to take responsibility for the entire value chain. From where do we source the raw materials and whom does it affect?

As demand for batteries increases as we transition from fossil-fuelled vehicles and production processes to electric ones, the manufacturing processes and materials used in battery production will play an ever greater role, both

in terms of climate impact and as an instrument of power. We must remain vigilant not to simply trade one harmful dependency for another one, and once again put our fate in the hands of unreliable partners. Together, Russia and China account for a massive majority share of the global market for both the production and extraction of rare earth metals and minerals needed for battery manufacturing. The threats to the climate and to democracy remain closely intertwined.

In recent years, we have learned that the path toward sustainability will not be a straight one. Unforeseeable events will occur, and we, along with the rules and laws we draft, must be able to adapt as the reality around us changes. That said, the goal must remain firm, the batteries we use in Europe must be sustainable, safe, and must not place us in harmful dependencies on countries that could use them against us.

I am deeply grateful to ELF for producing this publication, which comes at a time when it is becoming increasingly clear that security policy, sustainability, and competitiveness go hand in hand. I hope that, like me, you will gain a deeper understanding of the complex dilemmas surrounding the battery issue in 2025, as highlighted in the following chapters.

Karin Karlsbro
MEP, Renew Europe Group

EXECUTIVE SUMMARY

At the heart of Europe's shift to clean and competitive mobility lies a single technology: the battery. How Europe builds, finances, and governs the battery industry will determine not only whether it meets its 2050 climate goals, but also whether it can maintain competitiveness, strategic autonomy, and social cohesion in a rapidly electrifying world.

Setting the Scene - Europe's Battery Race and its Trade-offs

(Chapter 1)

Europe's ambition to decarbonise its transport system is as much an industrial challenge as a climate one. The path to clean transportation in Europe leads through electric vehicles (EVs). Road transport accounts for around a fifth of the EU's total CO2 emissions and it remains its most stubborn source. Reducing the sector's emissions is essential to achieve the EU's goal of becoming climate-neutral by 2050 and wide-scale adoption of EVs is a key component of the plan. However Europe's car industry has fallen behind in terms of electrification. The EU has increased support for the expansion of European EVs, but still relies heavily on imported batteries and foreign manufacturers. Batteries are the most technologically advanced and expensive parts of EVs, accounting for up to 50% of total vehicle costs. China dominates in both producing advanced batteries and processing raw materials, which are needed for their production. This raises issues regarding Europe's strategic autonomy and competitiveness. Amidst the current geopolitical context, developing sufficient domestic battery production capacity is of strategic importance to the EU. The continent's pursuit of "battery sovereignty" however demands trade-offs between technological independence and ecological responsibility, industrial speed and social fairness, innovation and cohesion.

Europe's drive to expand its battery industry is, at its core a struggle to reconcile ambition with principle. There are multiple critical questions for policymakers as Europe faces this complex balancing act;

- How can Europe most effectively support its EV industry in closing the electrification gap with global leaders?
- How to secure rare earth minerals and materials that are crucial to battery production amidst soaring needs and geopolitical tensions?
- What environmental price is Europe and its citizens willing to pay for increased domestic material extraction?
- How to mitigate the environmental and health impact of battery manufacturing in Europe?
- How to prevent a race to the bottom regarding pollution and work quality?
- Which battery chemistries, technologies and processes merit the largest investments?
- How can the costs and benefits of battery manufacturing be shared fairly among member states?

Lessons from Case Study 1 - The Silk Road's Electric Extension CATL's Adventures on European Soil

(Chapter 2)

One company, two sites, two realities. Contemporary Amperex Technology Co., Limited (CATL), is the world's largest lithium-ion battery manufacturer and a dominant global actor in the energy storage industry. The Chinese

battery manufacturer operates two factories just 860 kilometers from each other within the EU; one in Arnstadt, Germany and another in Debrecen, Hungary. This case study examines how CATL changes its operational and compliance practices when running large-scale battery manufacturing facilities under different regulatory and institutional environments within the EU. Europe's battery ambitions hinge on a fragile balance between industrial acceleration and regulatory integrity. If that balance fails, Europe risks a fragmented battery landscape shaped by uneven enforcement, regulatory competition, and, in some cases, a race to the bottom. Such discrepancies can undermine the EU's stated ambition to lead the world in clean, fair, and responsible industrial production.

CATL's behaviour is a symptom of structural weaknesses in the EU's governance framework. Altogether CATL demonstrates a sophisticated adaptive governance strategy; it calibrates its operational practices to

The EU could mitigate regulatory arbitrage and race to the bottom in the battery industry by tackling uneven enforcement, disparities in institutional quality, fragmented oversight, and loopholes created for national competition for investment.

- Although most laws are harmonized across EU countries, enforcement is left to national authorities, enabling regulatory arbitrage.
- There is a lack of supranational oversight. The EU's monitoring mechanisms focus on legislative transposition rather than implementation quality.
- Hungary has institutional limitations in oversight due to the dismantling of the Ministry for Environment in 2010, while Germany has mature bureaucracy and high institutional quality.
- Member states can create gaps and loopholes - accidentally or on purpose - like the permissive legal environment of the Special Economic Zone status in Hungary.

match the regulatory strength, institutional capacity, and social standards of each jurisdiction. In Arnstadt, Germany, the company operates within a mature institutional and regulatory environment characterized by robust environmental assessment requirements, established public consultation mechanisms, and trade union presence. Thuringia attaches explicit conditions and standards to state aid, while the regulatory environment emphasizes environmental and safety standards. Conversely, in Debrecen, Hungary, CATL exploits a more permissive regulatory environment created mainly by the government's Special Economic Zone framework. This exempts the plant from various Hungarian regulations and permits including local community consultations, legal means for municipalities to oppose the plans, and even certain environmental approval procedures. The company also took advantage of the Hungarian authorities' partiality regarding enforcement and weakened monitoring and oversight capacity since the dismantling of the Ministry for Environment.

Lessons from Case Study 2 - A South-Korean Superstar and a would-have-been European Champion

(Chapter 3)

The Asian and the European model. This case study compares Samsung SDI's battery factory in Göd, Hungary, and Northvolt's battery factory in Skellefteå, Sweden to examine the strategic and operational differences along with their broader environmental, employment and economic impacts. An added complexity to the story is that in March 2025 Northvolt filed for bankruptcy. As demand for electric vehicles slowed down in 2024 Northvolt faced severe financial, logistical and technical challenges. It was a young and emerging company without well-established links to industry and higher product costs than Asian manufacturers. Samsung also experienced a challenging year in 2024, but as a mature global company, it was able to shelter its battery-production arm; the majority of the factory's output was exported to the parent company.

Exploring these completely different models for localising battery production can help Europe in finding the right strategy and policies moving forward. While Samsung's model delivered operational continuity and cost competitiveness, it did so at the expense of environmental integrity, community trust, and technological autonomy. Northvolt's approach embodied European sustainability values and innovation ambitions but ultimately could not overcome market pressures and operational challenges. The failure - in some aspects - of both models suggests that Europe must develop a new framework that integrates rigorous environmental governance with industrial viability, balancing foreign investment with domestic capacity building to achieve genuine strategic autonomy in the battery sector. The production of batteries within EU borders does not result in automatic technological spillover or clean production. At the same time sustaining European industrial champions in the field is difficult even with state support due to cost competitiveness issues, pressured market dynamics and the strength of competitor companies.

Comparing the two approaches can teach Europe valuable lessons about balancing competitiveness, sustainability, and strategic autonomy in its clean-tech transition.

- **Technological spillover:** Northvolt's strategy focused on next-generation battery technologies that could provide European manufacturers with competitive advantage. Samsung's R&D center in Göd in contrast focuses primarily on process optimization, while the core intellectual property and innovation capabilities remain in its Asian operations.
- **Resource intensity:** The Samsung SDI site is one of Hungary's most resource-intensive industrial sites. Northvolt's operations were highly sustainable, with production based on 100% renewable electricity. The site also hosted a recycling plant to recover materials, aiming for 50% recycled content in cells by 2030.
- **Toxic pollution:** Samsung's Göd factory has a documented history of harmful pollution consistently surpassing limits since its establishment. At the Northvolt site no major pollution incidents have been reported, minor spills and emissions were swiftly contained in line with Swedish and EU regulations.
- **Relations with local community:** Residents and local authorities recognized Northvolt as a major driver of economic and social revitalization in the region, while Samsung has been in a constant battle with the local community.
- **Workers safety:** Samsung's Göd plant received operating permits despite workers' safety falling short of EU standards. Northvolt enforced a company-wide Health, Safety, and Environment roadmap with unified standards shared across all sites.

Outlook Key Factors that will Shape the Future of the Industry

(Chapter 4)

The global EV and battery market is entering a period of uncertainty and transformation driven by market consolidation, geopolitical tensions and technological disruption. Signs of these are already visible. Production of EV batteries far outpaces demand leading to bankruptcies, while China imposed export controls on various rare earth elements as a retaliation to US tariffs. Since industry forecasts assume consistent progression toward net-zero to 2050, any policy rollback would trigger a fall in projected EV demand and along the supply.

2025-2030 will be characterised by further geographic and industry concentration. Battery prices already dropped by an average of 20% in

Key trends that will shape the future of the industry in the next decades;

- Weaker than expected demand for EVs and oversupply is causing intense consolidation in the battery market
- Resource needs will soar beyond current mining capacity in the near future.
- Advancements in recycling could cover half of the EU's demand in certain raw materials for battery production.
- Next generation battery technology will bring down costs and reliance on rare-earth minerals.
- Innovations in manufacturing of batteries will improve safety, efficiency and reduce adverse environmental impact.
- The battery industry's trajectory through 2040 will depend critically on climate policy commitments.

2024, with Chinese companies likely involved in a domestic price-war to hog market shares. The most probable near-term scenario involves further consolidation of the China-centric battery ecosystem due to competitive pressures. Trade wars and escalating geopolitical tensions might hamper access to Chinese controlled rare earth materials and products. This creates a challenging environment for non-Chinese manufacturers to enter the market or compete in the near future.

Over the period between 2030 and 2035 resource needs peak, while technology reshapes the industry. Resource needs are expected to peak during the mid-2030s with China controlling 80-90% of certain materials and their processing. Global supply chains will increasingly shorten and regionalize along geopolitical lines. Trade barriers are likely to force Chinese manufacturers to establish production facilities in key markets to maintain access. Meanwhile technological advancements continue to improve manufacturing and battery efficiency. Advances in next-generation battery technologies promise both cost reductions and enhanced supply-chain resilience, while innovations in manufacturing are poised to boost safety and reduce the environmental footprint of production. By the mid 2030s battery recycling will evolve from a waste management necessity into a strategic material supply industry worth nearly $100 billion. New types of batteries and battery recycling technologies can create an opportunity for European manufacturers to compete on technology rather than cost.

Between 2035 and 2040 the industry matures bringing more balanced regional market shares. By 2040, the battery industry is likely to evolve into a mature market with established regional champions. Global demand is projected to finally absorb overcapacity and potentially even create some supply constraints. China's market share is projected to decline to 50%, however Chinese manufacturers will maintain technological leadership in key segments. Resource needs continue to soar, but recycling will become a major industry segment, satisfying up to 50% of the EU's demand in certain critical raw materials by 2040.

KEY POLICY RECOMMENDATIONS

Europe has to find the right EV and battery strategy amidst market consolidation, geopolitical tensions, regulatory changes and technological disruption. Europe faces a complex challenge as the global EV and battery market is entering a period of transformation and uncertainty. The European car industry is of strategic importance in terms of both jobs and GDP. Electrification is a key field, where important advances will be the source of a competitive advantage in the near future. Europe has to narrow the technology gap over time, but its battery ambitions also hinge on a fragile balance between industrial acceleration and regulatory integrity. A larger European battery industry could catalyze job creation across manufacturing, research & development, and downstream services. Beyond electric vehicles, a diversified battery ecosystem has potential applications such as light electric vehicles, renewable energy storages, and consumer electronics. Europe could also be a global leader in recycling technologies and transformation toward a circular economy. By aligning strategic investment, technological innovation, and environmental safeguards, the EU can transform its battery ambitions into a driver of sustainable growth and technological sovereignty. How Europe builds, finances, and governs the battery industry will determine not only whether it meets its 2050 climate goals, but also whether it can maintain competitiveness, strategic autonomy, and social cohesion in a rapidly electrifying world.

Four experts conducted an inquiry into what kind of industrial, climate and environmental model Europe should be building in its race toward electrification. Chapters 5-8 examine the strategic autonomy, environmental, climate and technology aspects of the question and provide specific policy recommendations from their fields'.

Local Factories, Foreign Control: Strategic Autonomy and Value Chains in the EU's Battery Rollout

(Chapter 5)

1. **Pursue Conditional Openness with Spillover Requirements:**
The EU must shift from pursuing battery capacity at any cost to governing foreign investments strategically through conditional openness. Chinese technological dominance makes complete autarky unrealistic. Openness to FDI including from China can accelerate capacity built-out and secure supply. However without conditions, it risks locking Europe into low value-added positions. Any public support, whether in the form of subsidies, infrastructure provision, or fast-track permitting should be contingent on measurable spillovers. These can include technology transfer, co-location of R&D, integration of local suppliers, and workforce training. Deep-pocketed incumbents can afford to walk away from subsidies if they dislike the terms, so conditions must be embedded in broader project approvals and regulatory frameworks, not just tied to grants.

2. **Coordinate Subsidies Strategically Across the EU:**
Amidst the looser state-aid rules since 2020 EU member states engage in a race to the bottom while end up funding both domestic champions and their most advanced foreign competitors. A coordinated EU-level governance framework for subsidies should set common conditionality standards, prioritise upgrading over mere capacity, and target critical gaps in the value chain. By aligning national incentives with shared strategic objectives, the EU can avoid duplicative investments and ensure public funds strengthen sovereignty rather than dilute it.

3. **Build and Retain Domestic Champions:**
Supporting domestic champions requires more than initial project funding,

it demands patient capital and political backing. National governments and EU institutions should be willing to take equity stakes, offer low-cost loans, and guarantee demand for strategically important producers. A deep local ecosystem is the best way to capture technological spillovers from incumbents, therefore domestic firms should be supported throughout the value chain.

4. **Enforce EU Regulations and Standards in all Member States:**
The EU must enforce its own rules to manage political, environmental, and social risks within its borders. Rule-of-law conditionality must be applied consistently, including to counteract the clear political risk from a geopolitically misaligned, autocratic member state. Environmental and labor standards must be upheld uniformly, with strong enforcement mechanisms, to prevent the ongoing race to the bottom in which member states undercut each other on safeguards to attract investment.

Environmental rotection: The Hidden Costs of European Battery Manufacturing

(Chapter 6)

1. **Limit and Substitute Toxic Substances:**
Environmental limit values for hazardous substances used in lithium-ion battery production, should be established at the EU level. These should also be taken into account when classifying hazardous installations under the Seveso Directive. Currently some of the particularly hazardous chemicals applied in production (NMP) are not covered as a result certain battery

factories are not officially categorized as hazardous facilities. The EU regulation within the REACH framework, which requires the substitution of hazardous substances with safer alternatives, should be enforced much more rigorously. In the case of battery plants, safer materials and technologies do exist, and their application should be much more strongly promoted both by EU rules and by national authorities.

2. Brownfield Investments are Greener:

Battery production plants should be authorised worldwide on brownfield sites, at a safe distance from residential areas. Numerous contaminated areas, left behind by earlier industrial activities, are awaiting remediation and reuse, and could provide suitable sites for such facilities. Meanwhile, so-called industrial "no-go zones," such as primary forests or water protection areas, must enjoy special protection.

3. Enforce the Aarhus Convention Across the EU:

The involvement of local communities in battery factory permitting procedures is essential as it involves handling toxic substances in near proximity of their homes. The Aarhus Convention, ratified by the EU guarantees citizens the right to access environmental information, participate in decision-making, and seek legal remedy. In practice, however, these requirements are often not met. Governments should not be able to fast-track permits for "nationally significant" projects that bypass independent environmental assessments and meaningful community consultation.

4. Rethink Mobility:

Although phasing out internal combustion vehicles and meeting climate goals requires electric cars (and batteries), the overall number of cars on the road must be reduced. This can be achieved through investments in affordable public transport powered by renewable energy, the promotion of cycling and walking, and reducing dependence on private vehicles. Meanwhile, cities must be designed so that all essential services are within easy reach, avoiding the need for private car use. Where driving is necessary, alternatives such as car-sharing should be available, as they also help reduce the number of private vehicles and thereby mitigate raw material demand.

Technology, Industry and Competitiveness: Balancing Ambition with Reality in Europe's Battery Push

(Chapter 7)

1. Avoid "Gigafactory Fetishism":

The EU should avoid focusing narrowly on building gigafactories. Instead it should embrace a more holistic industrial strategy that doesn't rely on a single technological pathway. The EU should prioritise smaller, more agile manufacturing hubs; factories that are adaptable, resource-efficient, and capable of producing smart, sustainable batteries aligned with emerging technologies. This diversified, innovation-led approach will better position Europe to catch up and also lead in the global battery race.

2. Build on Europe's Competitive Advantage in Circular Economy:

The EU should double down on its existing advantages in recycling and circular economy principles to gain competitive advantage over other global players. Temporary subsidies targeted to developing long-term competitiveness can act as a defensive tool against further erosion of Europe's industrial base and shelter future European champions.

3. Promote the "Right-Sizing" of Batteries:

Encourage the production of appropriately sized batteries rather than defaulting to ever-larger units in order to conserve critical materials and improve resource efficiency.

4. Accelerate Innovation in Emerging Technologies:

Foster innovation in low-carbon technologies and circular practices. Invest in next-generation battery chemistry technologies such as sodium-ion and solid state batteries. Support complementary technologies including smart grid infrastructure and alternative clean transport solutions that will allow for an energy transition that is not held hostage by a single technological pathway.

Climate Change: Aligning Battery Production with EU Climate Objectives

(Chapter 8)

1. **Place Gigafactories Strategically:**
Europe should prioritize locating gigafactories in regions with low-carbon electricity such as Sweden and France to reduce lifecycle emissions. Policies should also prevent deforestation for battery infrastructure and promote brownfield investments.

2. **Enforce Rigorous Lifecycle Emissions Reporting:**
EU institutions must establish full supply chain transparency, from mining impacts to manufacturer carbon footprints to site-specific emissions including energy mix and heat source. While the EU Battery Regulation enforces and requires carbon footprint reporting, the data has not been sufficiently disclosed publicly. For better policies and enforcement it would be beneficial to have easily accessible, public inventory of data from battery production sites. Standardized lifecycle greenhouse gas reporting also has to be enforced across the EU battery supply chain.

3. **Decarbonize the Electricity Grid:**
The source of the electricity used affects emissions from battery production, recycling, and whether production emissions can be offset through the battery electric vehicle lifecycle. Mandate renewable energy sourcing for battery manufacturing through Power Purchase Agreements (PPAs) or on-site generation. Using renewable energy in battery production, emissions can be reduced by 30% to 50%.

4. **Reduce Pollution Outsourcing:**
Bringing battery supply chains to Europe and requiring them to comply with EU's stringent environmental standards would prevent pollution export, and support climate justice.

Chapter 1

Setting the Scene - Europe's Battery Race and its Trade-offs

Tamás Jakab
Environmental Economist

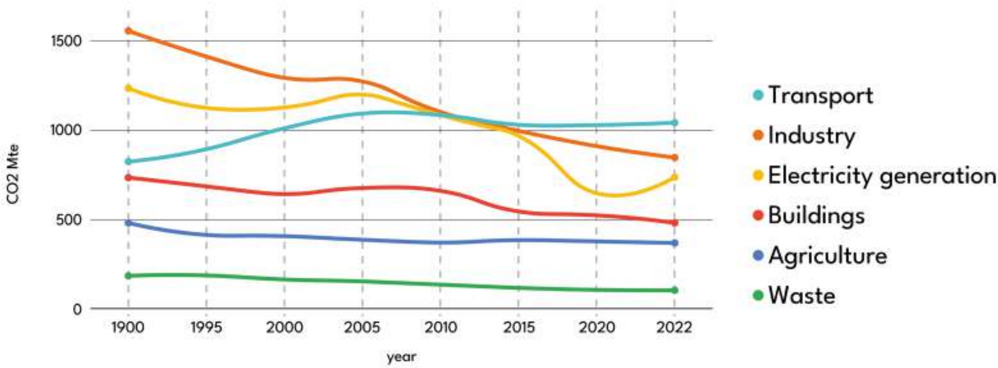
Anna Vindics
Policy Analyst

Europe's ambition to decarbonise its transport system is as much an industrial challenge as a climate one. Road transport remains the continent's most stubborn source of emissions, and the circulatory system of its economy and society. At the heart of Europe's shift to clean and competitive mobility lies a single technology: the battery. How Europe builds, finances, and governs this industry will determine not only whether it meets its 2050 climate goals, but also whether it can maintain competitiveness, strategic autonomy, and social cohesion in a rapidly electrifying world. The chapter traces this balancing act from the challenge of decarbonising Europe's transport system, through the Union's efforts to build a competitive and resilient battery sector, to the complex trade-offs that this ambition entails.

1. The Path to Clean Transportation in Europe leads through Electric Vehicles

Road transport is both Europe’s economic lifeline and its biggest climate liability. Road transport accounts for around a fifth of the EU’s total CO2 emissions and it keeps increasing (Figure 1). The transport sector is contributing around 5% to the EU’s GDP and it is employing more than 5% of the EU’s workforce, around 10 million people[1]. It carries the bulk of goods and people that keep the single market moving, yet it also produces nearly a third (30%) of the Union’s greenhouse gas emissions. This is more than any other sector, and its greenhouse footprint is still rising. (Figure 2). Road transport accounts for almost three quarters (74%) of emissions generated by the transport sector, and 21% of the total EU greenhouse gas emissions.

Figure 1: Greenhouse gas emissions by sector in the EU between 1990-2022



The figure shows the emissions in CO2 equivalent (in Megatons) Source: https://www.transportenvironment.org/state-of-european-transport/state-of-transport

1 European Commission (2025), ‘Transport and the Green Deal’ https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/transport-and-green-deal_e

As for the other modes of transport; around 15% is from shipping, another 11% is from aviation and only 0,4% is from railway[2]. These emissions primarily stem from two main categories, passenger transport and freight transport. Within road transport, passenger cars are the biggest contributors, making up 43.5% of road transport emissions[3]. Passenger cars alone account for almost 13% of total EU emissions, underscoring why decarbonising transport is central to Europe's climate agenda. Heavy-duty trucks and buses account for another 6%, and light-duty trucks contribute 2,5%.

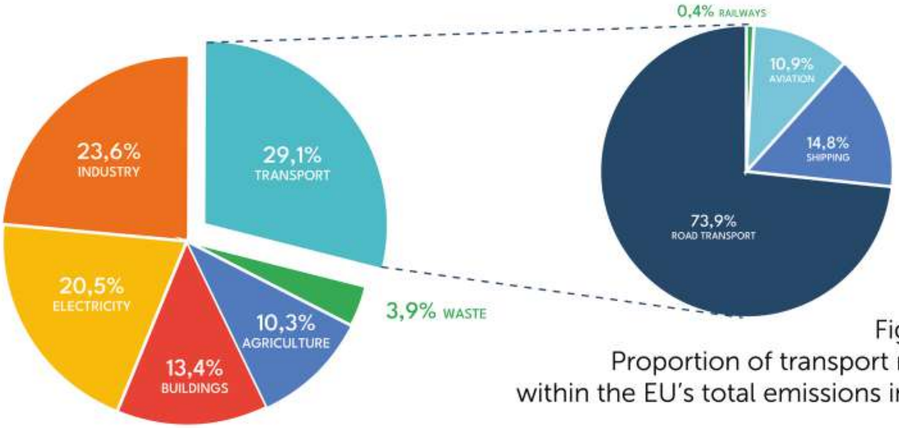


Figure 2:
Proportion of transport modes within the EU's total emissions in 2022

Note: The figure shows the emissions in CO2 equivalent (in megatons). A. The ratio of sectors within the total emission. B. The ratio of transport modes within total transport emission. Road transport makes about 21% of the total EU greenhouse gas emissions Source: https://www.transportenvironment.org/state-of-european-transport/state-of-transport

2 Transport & Environment (2024), 'State of European Transport 2024. T&E. An overview of the EU's largest climate problem', https://www.transportenvironment.org/state-of-european-transport/state-of-transport

3 German Federal Statistical Office (2025), 'Road transport: EU-wide carbon dioxide emissions since 1990', https://www.destatis.de/Europa/EN/Topic/Environment-energy/CarbonDioxideRoadTransport.html

Reducing emissions from road transport is key to achieving the EU's goal of becoming climate-neutral by 2050.[4] The European Green Deal adopted in 2020 aims to achieve EU climate neutrality by 2050. It outlines ambitious changes in the sector towards 'sustainable and smart mobility' including in fuels, emission standards, traffic management systems, public transport and freight delivery methods. Due to the large share of the transport sector in overall emissions, the Green Deal requires a 90% reduction in transport-related greenhouse gas emissions by 2050. In order to achieve this, an overall shift to clean transportation is necessary, which entails the transition to sustainable mobility solutions including battery electric vehicles (BEVs), hydrogen fuel cells and alternative fuels reducing reliance on fossil fuels. The 2021 European Climate Law sets an intermediate goal for 2030, namely that greenhouse gas emissions should be 55% lower compared to 1990 and details on how to achieve this. This is the Fit for 55 package, which among various sectors (aviation, land use, construction) also focuses on clean transportation. It sets emission reduction standards for member states, CO2 emission standards for cars and vans and outlines the development of alternative fuels infrastructure. The latter entails building the necessary electric charging stations as well as hydrogen and liquefied methane refuelling stations to support the EU's climate goals and achieve climate neutrality by 2050. The EU also accepted in 2022 that all new cars and vans sold in the EU as of 2035 should not produce any CO2 emissions.

A key component of the EU's plan to achieve this ambitious reduction of road transport emissions is increased domestic battery production. Batteries are the core element of electric vehicles; they store and supply all the energy that is needed to power the electric motor. Unlike internal combustion engine vehicles, where energy is continuously generated from fuel, the performance of EVs rely entirely on their batteries. This component determines the driving range, the weight of the vehicle, charging speed, as well as the design of the vehicle. Batteries are also the most expensive part

4 European Parliament (2024), 'Fit for 55 package', https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733513/EPRS_BRI(2022)733513_EN.pdf

of an EV, accounting for up to 50% of total vehicle costs.[5] Because of the higher energy efficiency of EVs compared to internal combustion engines, shifting from fossil fuels to electric sources not only reduces tailpipe emissions[6], but also increases efficiency. As a result, if the electricity used originates from renewable, green energy sources, it completely eliminates greenhouse gas emissions such as CO2 as well as other air pollutants. At the moment battery-powered EVs are cheaper than hydrogen-powered cars and they also need less new infrastructure as nationwide electrical grids already exist[7]. Electrification in the transport sector would also include large-scale electrification of railroads and public transport. With the continuous decarbonization of electricity production, it is expected that a higher proportion of clean energy would be used within the transport sector as well. Since the primary focus of this publication is battery production, these other aspects will only be addressed briefly.

Europe's car industry has fallen behind in terms of electrification. Electrification is a key field, where important advances will be the source of a competitive advantage in the near future. Europe's EV car sales originate mostly from European production, but that might change due to high EV prices. German carmakers like Volkswagen and BMW remain important car producers, but face growing competition and erosion of market shares. The German carmaking industry has lost around 6% of total jobs in a year mainly due to the transition to EVs, which require less manpower to build and more competition from China. Europe is also developing its battery supply chain,

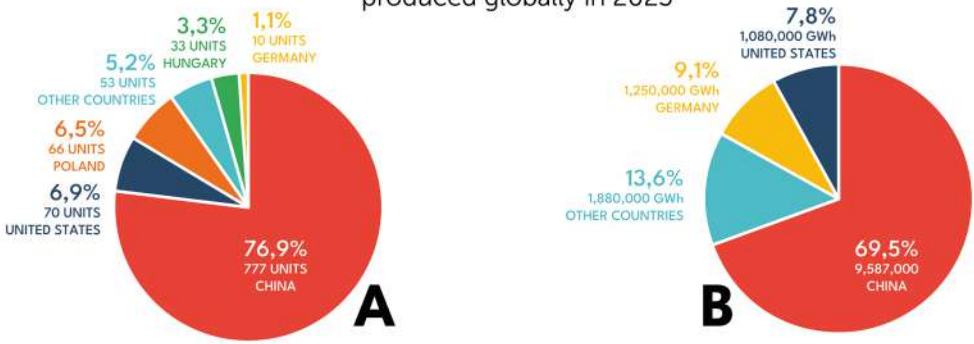
5 N., Carey, P. Lienert, & S. Mcfarlane (2023), 'Insight: Scratched EV battery? Your insurer may have to junk the whole car' Reuters, https://www.reuters.com/business/autos-transportation/scratched-ev-battery-your-insurer-may-have-junk-whole-car-2023-03-20/

6 T. Gustafsson, A. Johansson (2015) 'Comparison between battery electric vehicles and internal combustion engine vehicles fueled by electrofuels'. Master's Thesis, Chalmers University of Technology, Gothenburg, Sweden ; Helmers E, Marx P (2012) 'Electric cars: technical characteristics and environmental impacts', Environ Sci Eur 24(1):14

7 MIT Climate Portal (2023), 'Why have electric vehicles won out over hydrogen cars (so far)?', https://climate.mit.edu/ask-mit/why-have-electric-vehicles-won-out-over-hydrogen-cars-so-far

particularly in countries like Germany, Poland, and Hungary, yet struggles to match China's scale and cost advantages. The global electric vehicle industry is dominated by China leading in both EV production, battery manufacturing (Figure 3) and rare-earth refining. China produces 80% of battery cells globally, while controlling 85% of cathode and 90% of anode materials, which are key ingredients of batteries. EVs make up a much larger share of car sales in China than in Europe. However, Chinese manufacturers also look for overseas markets to sell their EVs and batteries. Competition is heating up as manufacturing capacity of EV batteries reached 2,6 TWh in 2024, more than double the demand[8 9].

Figure 3:
Number of electric vehicles (A) and Gwh of battery cells (B) produced globally in 2023



Note: A. EV production in units. B. Battery cell production in GWh. Other countries include those manufacturing countries whose contribution to global production is less than 1% (A: Japan, South Korea, France, UK, Spain, Poland, Czech Republic, Belgium, Italy, Turkey, India, Mexico, and Canada; B: Japan and South Korea).
Source: https://www.transportenvironment.org/state-of-european-transport/state-of-transport

8 M. Reid (2025), 'China's overcapacity: Will its battery industry consolidate?', CRU Group. CRU Group Website, https://www.crugroup.com/en/communities/thought-leadership/2025/chinas-overcapacity-will-its-battery-industry-consolidate/

9 C. McKerracher (2024), 'China Already Makes as Many Batteries as the Entire World Wants', BloombergNEF, https://about.bnef.com/insights/clean-transport/china-already-makes-as-many-batteries-as-the-entire-world-wants/

2. Europe's Dependence on Imported Batteries and Raw Materials has Become a Test of its Industrial Capacity and Geopolitical Independence

In the current geopolitical context developing sufficient domestic battery production capacity is of strategic importance to the EU. As the shift towards electric vehicles accelerates, car manufacturers based in the EU will require a rapidly growing volume of batteries to meet demand. The EU's outlook on battery production is characterized by a strong ambition to establish a competitive industry in order to fulfil these increasing domestic needs. Securing domestic battery production is not only vital for the success of the EU's clean mobility transition but also for safeguarding industrial competitiveness and strategic autonomy. Battery production is a high-tech industry requiring multiple rare earth minerals, which makes this aspect of EV production particularly sensitive. It is of strategic importance who possesses or has access to key technology and materials. The current reliance on non-EU countries for battery manufacturing, created significant external dependencies, posing both economic and geopolitical risks. The COVID19 crisis exposed how vulnerable long supply chains can be amid current geopolitical tensions. Despite efforts to diversify, the EU remains heavily reliant on imports for critical raw materials like lithium, cobalt, and natural graphite, which are essential for battery production. Reliance on complex global supply chains for critical battery materials not only increases vulnerability to geopolitical tensions, but also raises concerns over labor conditions and environmental standards in supplier countries.

Increased battery production in the EU could drive job creation and economic competitiveness. The battery industry's value chain encompasses a wide range of activities from raw material extraction and processing, through advanced manufacturing of cells and modules, to system integration, recycling, and cutting-edge research and development. Onshoring these industries can support knowledge absorption, innovation and employment growth across varied skill levels. These expected benefits are frequently emphasized in EU-level strategies, national industrial plans, and corporate communication. In Germany, the federal government has framed battery gigafactory investments (such as those by Tesla in Grünheide) as part of a future-proof, sustainable industrial strategy despite local protests.[10] In Hungary, the government tried to sell East Asian battery investments (like CATL or Samsung in Debrecen) as major drivers of economic growth, employment and long-term industrial development. The case studies in chapter 3 and 4 discuss to what extent this has been the case and what additional questions these have raised about autonomy, governance, control, and technology transfer.

The EU has increased financial support for the expansion of European EVs. Historically, non-European manufacturers - including Tesla and certain Chinese companies - have captured a significant share of EU funding and EV incentives, alongside European producers, as they have been ahead of European manufacturers both in terms of production capacity and integration into supply chains. Tesla for example already had a gigafactory in Germany when German carmakers still lobbied for internal combustion engines. Meanwhile both Tesla and Chinese battery makers receive strong support and heavy subsidies at home.[11] This makes them able to produce at lower costs, giving them a competitive advantage over European manufacturers. In 2024 France, Germany and Sweden jointly called on the European Commission to back domestic battery manufacturing to reduce reliance, particularly on China.[12] To address these issues the EU committed to support European battery manufacturing with an overall

10 Germany: Tesla given go-ahead for Berlin factory expansion – DW – 07/04/2024. https://www.dw.com/en/germany-tesla-given-go-ahead-for-berlin-factory-expansion/a-69564599

11 D. Butler, T. Thadani, E. Martinez, A. Gregg, L. Melgar, J. O'Connell and D. Keating (2025): 'Elon Musk's business empire is built on $38 billion in government funding', The Washington Post, https://archive.ph/9qz80

12 P. Blenkinsop (2024), 'France, Germany, Sweden urge EU battery sector push to avoid China reliance', Reuters, https://www.reuters.com/technology/france-germany-sweden-urge-eu-battery-sector-push-avoid-china-reliance-2024-11-28/

investment of 4.6 billion euros.[13] The Innovation Fund 2024 dedicated a call for EV battery manufacturing to incentivise investment, boost demand and make the industry more competitive and resilient by reducing the risk of dependency on foreign suppliers for this strategic technology.[14] Moreover, the 2025 relaxation of EU state aid rules allows for grants, tax breaks and loan guarantees specifically targeting green industries like battery production. The new rules will make it easier for pension funds, insurers and other private investors to co-invest in green projects.[15] Still, maintaining competitiveness in the current global race will be really challenging against the Chinese, Korean and US battery producers.

Europe's battery strategy reflects broader geopolitical tensions around technological sovereignty and supply chain security. The European Commission launched the European Battery Alliance (EBA) in October 2017 to address this industrial challenge. The EBA's goal was to "build a strong pan-European battery industry to capture a new market worth 250B€/year in 2025". The EU's battery strategy aims to achieve 90% self-sufficiency in battery cell production by 2030, requiring massive investment in domestic manufacturing capacity.[16] At the moment however, more than half of the planned battery production in the EU is still at risk of being delayed,

13 European Commission favours more EU funds for electric vehicles sector. Reuters (2024). https://www.reuters.com/business/autos-transportation/european-commission-favours-more-eu-funds-electric-vehicles-sector-2024-12-03/

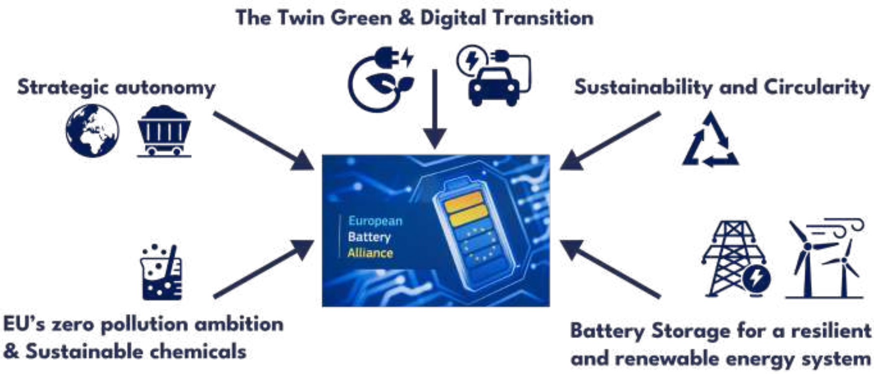
14 European Comission (2025), 'Innovation Fund 2024: Investing into the future of net-zero technologies and electric vehicle battery cell manufacturing', https://climate.ec.europa.eu/news-your-voice/news/innovation-fund-2024-investing-future-net-zero-technologies-and-electric-vehicle-battery-cell-2025-05-14_en

15 F. Y. Chee, & F. Y. Chee (2025), 'EU eases state aid rules to boost green projects, cut carbon footprint', Reuters, https://www.reuters.com/sustainability/boards-policy-regulation/eu-eases-state-aid-rules-boost-green-projects-cut-carbon-footprint-2025-06-25

16 G. Ragonnaud (2025), 'Powering the EU's future: Strengthening the battery industry', EPRS | European Parliamentary Research Service, https://www.europarl.europa.eu/RegData/etudes/BRIE/2025/767214/EPRS_BRI(2025)767214_EN.pdf

downsized or cancelled. The EU Batteries Regulation[17] of 2023 implements comprehensive lifecycle requirements from design to disposal, creating potential barriers for imports while supporting domestic manufacturers. Meanwhile the European raw materials strategy aims to reduce dependence on Chinese processing making circular economy strategies crucial for European competitiveness. The European Battery 2030+ initiative also requires the industry to shift towards chemistry-neutral research approaches to mitigate its adverse impact on environment and worker's health.

Figure 4: Batteries, a key technology in the green and digital transition, are at the centre of EU policymaking



Source: EU LEGISLATION & DIRECTIVES. European Battery Alliance https://www.eba250.com/legislation-market/eu-legislation/.

3. The Promise of Cleaner Mobility Collides with Environmental, Social, and Technological Dilemmas that will Shape the Future of Europe's Green Transition.

European leaders and policy-makers face complex trade-offs and externalities related to increased battery production. In order to ensure stable,

17 European Union Regulation (2023), '2023/1542 - EN - EUR-Lex.', https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng

sustainable and sufficient supply, the EU aims to produce a significant share of batteries within its own borders. However, achieving this is in conflict with other important goals of the EU making it a complex balancing act. There are considerable trade-offs in various areas and finding the right balance is not straightforward. There are many questions to consider, such as:

- How can Europe most effectively support its EV industry in closing the gap with global leaders? The European car industry is of strategic importance related to jobs and GDP. On top of this, electrification is a key field, where important advances will be the source of a competitive advantage in the near future. At this moment China and the US are in the forefront globally in terms of EV technology, while China dominates producing batteries and processing raw materials. It is important to make sure that the technology gap narrows over time. Knowledge spillovers are needed from overseas companies as well as European or national public support for the industry.
- What environmental price is the EU and its citizens willing to pay for increased domestic material extraction? The environmental footprint of the extraction of critical raw materials and the operation of large-scale manufacturing plants is considerable. The shift to electric vehicles requires more raw materials - such as lithium, cobalt, and nickel - than conventional cars. This drives demand for new mining projects and amplifies local environmental and social impacts in resource-rich regions. Lithium extraction is often conducted through water-intensive evaporation ponds or open-pit mining, which can lead to soil degradation, biodiversity loss, and depletion of freshwater resources.
- How to secure rare earth minerals and materials that are crucial to battery production? Australia and Canada have the greatest potential for providing low-risk supply of such materials to the EU. Still, covering demand looks challenging as lithium, nickel, and graphite needs are projected to increase by 14, 20, and 19 times respectively by 2040. Waste to value transformations and recycling of batteries can become a major source for European material needs balancing the equation.
- How to mitigate the environmental and health impact of battery

production? Battery plants are not only extremely water-intensive but in many documented cases they also contaminate nearby water sources. In Hungary, chemicals used for the battery manufacturing process were found in nearby groundwater. Residents documented multiple cases of toxic byproducts exceeding healthy limits posing risks to human health in the soil, water and air.[18]

- How to prevent a race to the bottom regarding work quality? Battery manufacturing is often promoted as a catalyst for green jobs and the renewal of industry.However, its social and labour related externalities require a closer look. In several cases workers faced inadequate safety standards, developed serious health conditions and generally entered low quality jobs. Furthermore, these jobs touted as innovative, often turn out to be menial. There are also concerns regarding the treatment of foreign and temporary workers and enforcement of worker's rights.
- How to distribute costs and benefits fairly across the EU? France, Germany, and Sweden received the majority of EU support, both in terms of technological development and financial investment. On the other hand, Eastern and Central European nations such as Poland and Hungary face structural disadvantages. Their reliance on fossil fuel based electricity prevents them from being certified as "green" battery production under EU directives.
- Which technologies to invest in? NMC (nickel manganese cobalt oxide) and NCA (nickel cobalt aluminium oxide) batteries have long dominated the market, but their future dominance is increasingly uncertain as LFP (lithium iron phosphate) technology gains ground due to lower material costs and availability.[19]

18 Zs. Bodnár (2024), 'Göd battery factory: 88 tonnes of fetotoxic solvents in the air, heavy metals in workers' immune systems', Átlátszó, https://english.atlatszo.hu/2024/02/27/god-battery-factory-88-tonnes-of-fetotoxic-solvents-in-the-air-heavy-metals-in-workers-immune-systems/

19 V. Weiler (2025), 'Összeesett a magyar akkugyártás, és ezért a benzines autókat okolják. A valóság sokkal durvább', telex, https://telex.hu/komplex/2025/06/23/akkumulatorgyartas-sk-on-samsung-catl-korea-kina-technologiavaltas

Europe's drive to expand its battery industry is, at its core, a struggle to reconcile ambition with principle. The dilemmas above are interconnected pieces of a wider question: can Europe scale up rapidly enough to compete with global leaders while staying true to its environmental, social, and economic values? The continent's pursuit of "battery sovereignty" thus demands trade-offs between technological independence and ecological responsibility, industrial speed and social fairness, innovation and cohesion. The chapters that follow examine these tensions in turn: Ch. 6 "Environmental Protection: The Hidden Costs of European Battery Manufacturing" assess the ecological limits of Europe's battery strategy; Ch. 5 "Local Factories, Foreign Control: Strategic Autonomy and Value Chains in the EU's Battery Rollout" analyse the geopolitical dependencies shaping it; "Technology, Industry and Competitiveness: Balancing Ambition with Reality in Europe's Battery Push" explores its industrial logic; and case studies on Samsung, Northvolt and two different CATL factories show how these abstract trade-offs manifest in practice. Together, they form a coherent inquiry into what kind of industrial and environmental model Europe should be building in its race toward electrification.

Chapter 2

Case Study 1: The Silk Road's Electric Extension CATL's Adventures on European Soil

This case study examines how CATL changes its operational and compliance practices when running large-scale battery manufacturing facilities under different regulatory and institutional environments within the EU. CATL's behaviour is not exceptional but symptomatic of structural weaknesses in the EU's governance framework. Europe's battery ambitions hinge on a fragile balance between industrial acceleration and regulatory integrity. If that balance fails, Europe risks a fragmented battery landscape shaped by uneven enforcement, regulatory competition, and, in some cases, a race to the bottom. CATL's two European factories offer a revealing glimpse into how that balance plays out in practice. CATL's Chinese origins also raise a question about whether localisation builds or blurs Europe's technological sovereignty.

One company, two sites, two realities. Contemporary Amperex Technology Co., Limited (CATL), a Chinese battery manufacturer operates two factories just 860 kilometers from each other within the EU. By comparing the factories in Debrecen and Arnstadt (Figure 1) the analysis reveals how a multinational company navigates the different administrative frameworks, environmental permitting systems, and labor regulations of Germany and Hungary. While both sites operate under EU laws, the national and regional interpretations, enforcement mechanisms, and political priorities are different, having profound implications on the running of the two sites.

Ensuring high environmental and social standards across all member states is crucial in preventing race to the bottom. While the EU has committed to building up its own capacity in clean energy technologies, success will depend on more than simply luring in major investments from global heavyweights like CATL. If the rules vary too much from one country to another, the door opens for regulatory arbitrage: firms making decisions not because a location is the most suitable or sustainable choice, but because it offers the least oversight. Such discrepancies can lead to a race to the bottom and undermine the EU's stated ambition to lead the world in clean, fair, and responsible industrial production.

CATL is the world's largest lithium-ion battery manufacturer and a dominant global actor in the energy storage industry.[20] Founded in 2011 in Ningde, Fujian Province, China, CATL has rapidly ascended to become the undisputed leader in the electric vehicle (EV) battery market. It held a commanding

20 L. Kang (2025), 'Global EV battery market share in 2024: CATL 37.9%, BYD 17.2%'. CnEVPost, https://cnevpost.com/2025/02/11/global-ev-battery-market-share-2024/

37.9% global market share in 2024, the only manufacturer exceeding 30%. The company has maintained its position as the world's top EV battery supplier consistently for the past eight years. CATL's market dominance extends beyond automotive applications. The company also leads the global energy storage industry with a 36.5% market share[21].[22] This dual leadership across both mobility and stationary energy storage positions CATL as a critical player in the global energy transition dominating critical battery supply chains. Due to an increasingly complex geopolitical environment the company now faces regulatory challenges, including EU tariffs on Chinese-made EVs and a place on the US's military-linked blacklists in January 2025. However, CATL's localization strategy through European manufacturing helps mitigate some trade barriers while maintaining access to key markets.[23] While CATL publicly commits to environmental standards, implementation appears less rigorous, with community concerns about water usage and environmental impacts receiving limited acknowledgement[24 25 26].

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21 Contemporary Amperex Technology Co. Limited (2020), LinkedIn, https://www.linkedin.com/company/contemporary-amperex-technology-gmbh

22 CATL (2025), 'Revenue for CATL (300750.SZ)', https://companiesmarketcap.com/catl/revenue/

23 G. Marino (2025), 'CATL, all you need to know about the Chinese battery giant making its stock market debut', Renewable Matter, https://www.renewablematter.eu/en/catl-all-you-need-to-know-about-the-chinese-battery-giant-making-its-stock-market-debut

24 Éltető A. (2023), 'Aspects of electric vehicle battery production in Hungary', ELRN Centre for Economic and Regional Studies Institute of World Economics, Working Paper Nr. 271, https://vgi.krtk.hu/wp-content/uploads/2023/06/Elteto_WP_271.pdf

25 Éltető A. (2024), 'Why Is It Different? Specific Characteristics of the Hungarian Battery Industry: Legal Background and Environmental Impacts', HUN-REN Centre for Economic and Regional Studies, Institute of World Economics, Working Paper Nr. 276 https://vgi.krtk.hu/wp-content/uploads/2024/08/Elteto_WP_276.pdf

26 CATL (2023), 'Environmental, Social and Governance (ESG) Report', https://www.catl.com/en/uploads/1/file/public/202404/20240417102933_uuiks9ljr8.pdf

Table 1: Comparison of key characteristics of the two battery factories, 2025		
ITEM	**ARNSTADT** (Thuringia, Germany)	**DEBRECEN** (Hajdú-Bihar, Hungary)
Investment (EUR)	ca. €2 billion	ca. €7.34 billion
State Aid	ca. €7.5 million (0.42% of total investment)	Promised €800 million (10.9% of total investment); not transferred yet
Infrastructure Cost	N/A	ca. €220 million(3% of total investment, part of the state aid)
Capacity (current / planned)	8 GWh currently; planned: 14 GWh (potentially 24 GWh)	Phase 1: 40 GWh; full capacity goal: 100 GWh
Jobs	Target: ~2000; In 2025: ~1000–1500[27]	Target: ~9000; In 2025: ~650; end of 2025 goal: ~2000
Construction Site Type	Brownfield (former Solarworld site, 34 ha, part of 70 ha site reserved for expansion)	Greenfield, new industrial area (221 ha)
Energy Supply	Solar panels on roof, green electricity, smart energy system	Planned carbon-neutral; renewable energy sources, storage solutions
Annual Power Consumption	N/A	Approx. 1,640 GWh (640 GWh electricity, 1000 GWh natural gas)[28]
Daily Water Usage	N/A	Average: ~3,378 m^3/day (peak: ~6,232 m^3/day); 85% evaporated; ~50% greywater use

27 H. Langguth (2025), 'Left-behind' amid the 'boom'? Large-scale green technology projects and reinforced peripheralisation in Eastern Germany', European Urban and Regional Studies, doi:10.1177/09697764251329313

28 Á. Kuki, C. Lakatos, L. Nagy, T. Nagy & S. Kéki (2025), 'Energy Use and Environmental Impact of Three Lithium-Ion Battery Factories with a Total Annual Capacity of 100 GWh.', Environments 12, 24, https://www.mdpi.com/2076-3298/12/1/24

Both locations have excellent transport infrastructure and were already host to relevant industrial players. Arnstadt benefits from direct access to motorways A4 and A71/73, with the airport in Erfurt just 20 km away, placing it within the technology triangle of Erfurt-Jena-Ilmenau. It already hosted Solarworld (whose former site CATL acquired), Thales Rail Signalling Solutions, and various manufacturing firms. Debrecen became an economic and logistical hub in Eastern Europe with good access to highways. It received investments from key players of the automotive industry such as BMW, Mercedes-Benz, Semcorp[29]. These features and industrial links made them attractive locations to CATL.

CATL received substantial government backing and support at both locations, but Germany posits stricter standards and requirements. Arnstadt benefited from subsidies by the state of Thuringia and promotional assistance from LEG Thuringia, a limited liability company (GmbH) associated with the Thuringian Ministry of Economy[30]. This together adds up to around €7.5 million, 0.42% of the total investment. Hungary provided even more generous support for the Debrecen facility, with a total of €800 million investment, including the infrastructural development of the Southern Economic Zone, where CATL is now located[31] amounting to 10.9% of the total investment. Thuringia attaches explicit conditions and standards to state aid. It offers structured investment promotion programs with clear criteria and transparent processes, including the Joint Task „Improvement of regional Business structure" and Regional Investment Program. The regulatory environment emphasizes environmental standards, with Thuringia

29 Q. M. Wu. (2024), 'The embrace and resistance of Chinese battery investments in Hungary: The case of CATL', Asia Eur J 22, 201–223, https://link.springer.com/content/pdf/10.1007/s10308-024-00699-9.pdf

30 A. Gagyi (2025), 'CATL, capitalist strategies and emerging state-capital alliances', Transnational Institute, https://www.tni.org/en/article/catl-capitalist-strategies-and-emerging-state-capital-alliances

31 Hungary Today (2023), 'Debrecen's Economic Zones Are Being Developed at Full Speed', https://hungarytoday.hu/debrecens-economic-zones-are-being-developed-at-full-speed/

already achieving nearly 40% renewable energy in its grid[32]. To meet the stricter standards, CATL equipped Arnstadt with one of the biggest dry room environments to date. With this advanced ventilation technology it created a workplace where air humidity can be carefully controlled.[33] This ensures better product quality while reducing the risk of internal short circuits and, more generally, the occurrence of explosions and battery fires. Hungary, conversely, introduced more permissive and accelerated procedures for the company on top of the vast financial support. The government has established Special Economic Zones exempting the plant from Hungarian regulations including local community consultation, legal means for municipalities to oppose the plans, and even certain environmental approval procedures and permits. Hungary's accelerated permitting for CATL illustrates the competitiveness vs. sustainability dilemma at its finest. Facing competition in battery production, Hungary positioned itself as the easy entry point for Far Eastern battery companies to European markets. This creates a two-tier European battery industry where sustainability can become optional rather than foundational.

There are significant differences in wages and local talent development across the two sites. Germany's hourly labor costs average €43.40, placing it 30% above the EU average, while Hungary's are just €14.1 per hour, among the lowest three in the EU[34] . This substantial cost differential partly explains why the plant in Debrecen is planned to employ almost five times as many employees as the one in Arnstadt[35] . Both sites emphasize local talent development, but with different approaches. CATL Arnstadt employs

32 CATL (2019), 'CATL starts construction of its first overseas factory in Germany', https://www.catl.com/en/news/473.html

33 Cleanroom Technology (2021), 'Caverion equips battery factory with ventilation technology', https://cleanroomtechnology.com/caverion-equips-battery-factory-with-ventilation-technology-178459

34 The Munich Eye (2025), 'Newspapers, T. E. Labor Costs in Germany Exceed EU Average at EUR43.40 per Hour', https://themunicheye.com/germany-labor-costs-exceed-eu-average-19970

35 S. Yanatma (2025), 'Labour costs across Europe: Where are they highest and lowest?', euronews, http://www.euronews.com/business/2025/04/19/labour-costs-across-europe-where-are-they-highest-and-lowest

1,700 people and is actively recruiting for 105 additional positions, while providing vocational training for around 30 people annually. The German facility benefits from highly qualified regional workforce and established educational partnerships. It employed 500 Chinese employees in 2024 (around 25% of workforce), which it aims to decrease to 100 in order to further localise the workforce.[36] The Debrecen facility relies heavily on foreign workers, with up to 30% of the workforce being employed through temporary work agencies[37]. It had around 500 employees in early-2025, targeting to reach 2000 by end-2025[38]. Although the company has established partnerships with local universities and vocational training centers, this ambitious recruitment effort seems impossible to cover through increased local employment as there are severe labor shortages.

Requirements differed markedly in terms of local public engagement. The German system maintains stronger public participation mechanisms and transparency requirements compared to Hungary's bare-bones online-only consultation processes[39]. In Debrecen, the CATL project faced highly contentious public hearings initially, with significant local opposition concerning water usage, environmental impact, and land rights. The government first tried to sway public opinion through state-controlled media. Municipal media controlled by the government (Dehir) published 57% positive coverage of the battery factory, while independent media (Debreciner) published 68% negative coverage. Finally the government established a Special Economic Zone for the facility that allowed the bypassing of local civic opposition. Environmental hearings have been

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36 J.D. Capelouto (2024), 'Inside a Chinese battery giant's plan to become 'more European', https://www.semafor.com/article/10/17/2024/inside-chinese-battery-giant-catls-plan-to-become-more-european

37 K. Bodor (2024), 'Foreign workers in Hungary – Key facts and labor market challenges . Labor and social justice', Fridrich Ebert Stiftung, https://library.fes.de/pdf-files/bueros/budapest/21810.pdf

38 Debrecen4U (2025), 'CATL ramps up battery production in Germany', https://debrecen4u.hu/catl-ramps-up-battery-production-in-germany/

39 A. Gagyi (2025), 'CATL, capitalist strategies and emerging state-capital alliances', Transnational Institute, https://www.tni.org/en/article/catl-capitalist-strategies-and-emerging-state-capital-alliances

reduced to online formats, limiting citizens' ability to actively participate in decision-making processes. The handling of the public consultation process puts growth above inclusion. Hungarian authorities held online only environmental hearings and streamlined procedures as necessary for rapid deployment of strategic infrastructure. Yet this growth-at-all-costs approach excluded Debrecen residents from meaningful participation in decisions affecting their water resources and environment.

CATL actively resisted worker representation efforts, but it received pushback from Germany's strong unions. In September 2024, CATL Arnstadt held its first works council election with 73.5% turnout among 1,853 eligible employees[40 41]. In November 2024, CATL terminated the employment of one of the candidates. This prompted strong objections from IG Metall, which asserted that the dismissal constituted a breach of Germany's Dismissal Protection Act. The union committed to provide full legal support to the affected employee. IG Metall also reported that CATL's management actively discouraged union representation by offering employees career advancement and promotion opportunities in exchange for withholding support for the works council. Currently, there are no known work councils at CATL's Debrecen plant, and union representation remains weak in Hungary. As electrification progresses, Hungarian trade unions - specifically the Chemical Workers' Union (VDSz) and the Metalworkers' Union (VASAS) - are intensifying efforts to organize workers in the new battery factories. Supported by the EU project 'Putting Trade Union Power into European Batteries' aimed at empowering unions in the battery sector, these unions have begun recruitment campaigns for representatives and engaged in social dialogue and wage negotiations first in 2025.[42] Yet, unions in Hungary

40 Mitte (2024), 'Betriebsratswahl bei CATL- Kandidaten der IG Metall können die meisten Stimmen auf sich vereinigen', https://www.igmetall-bezirk-mitte.de/aktuelles/meldung/betriebsratswahl-bei-catl-kandidaten-der-ig-metall-koennen-die-meisten-stimmen-auf-sich-vereinigen

41 MDR Thüringen (2024), 'CATL kündigt Betriebsrats-Kandidatin in Thüringen', https://www.mdr.de/nachrichten/thueringen/mitte-thueringen/arnstadt-ilmkreis/catl-kuendiugung-betriebsrat-100.html

42 industriAll (2025), 'Hungarian Unions plan to organise battery factories', https://news.industriall-europe.eu/Article/1300

remain weak. In addition over the past years the government became hostile against unions that protested against its policies by cutting their rights and limiting their membership. These divergent labour standards undermine European social cohesion and the EU's "just transition" vision.

CATL's behaviour is a symptom of structural weaknesses in the EU's governance framework. Altogether CATL demonstrates a sophisticated adaptive governance strategy; it calibrates its operational practices to match the regulatory strength, institutional capacity, and social standards of each jurisdiction. In Arnstadt, Germany, the company operates within a mature institutional and regulatory environment characterized by robust environmental assessment requirements, established public consultation mechanisms, and trade union presence. Conversely, in Debrecen, Hungary, CATL exploits a more permissive regulatory environment created mainly by the government's Special Economic Zone framework. The company also took advantage of the Hungarian authorities' partiality regarding enforcement and weakened monitoring and oversight capacity. Europe could learn from the German example (as a model for balancing competitiveness with integrity). The CATL case exposes the sovereignty vs. interdependence dilemma inherent in EU industrial policy. Hungary asserts its sovereign right to determine environmental procedures for investments within its borders, however CATL's Hungarian production enters the same integrated European supply chain as its German output. When batteries produced under different regulatory regimes compete in the same market, one country's sovereignty becomes another country's competitive disadvantage.

The EU could mitigate regulatory arbitrage and race to the bottom in the battery industry by tackling uneven enforcement, disparities in institutional quality, fragmented oversight, and loopholes created for national competition for investment.

- Uneven enforcement architecture: Although most laws are harmonized across EU countries, enforcement is left to national authorities, enabling regulatory arbitrage. The EU's Smart Enforcement policy is hampered by varying administrative capacity and political will. Hungary's centralized focus on economic growth is permissive towards FDI and industrial policy. This contrasts with Germany's rule of law approach taking into account the interests of various stakeholders.

- Disparities in administrative capacity: Research shows that administrative capacity constraints significantly affect policy implementation across EU states. Hungary has institutional limitations in environmental assessments due to the dismantling of the ministry for environment and defunding of monitoring and enforcement activities since the current government entered power in 2010. Meanwhile Germany's mature bureaucracy and high institutional quality provides extensive oversight.[43 44]
- Lack of supranational oversight: The EU's monitoring mechanisms focus on legislative transposition rather than implementation quality. The European Commission lacks resources to monitor the compliance of facilities, it relies on the reporting of member states. Member states can create enforcement gaps (accidentally or on purpose) like the permissive legal environment of Special Economic Zones in Hungary[45].
- Competition for investment: Aggressive competition for foreign investment between EU member states shows signs of a race to the bottom. Hungary's €300 million infrastructure investment and creation of a Special Economic Zone for CATL with permissive conditions is an

43 M. D. Crego, R. Mańko, W. van Ballegooij (2020), 'Protecting EU common values within the Member States. An overview of monitoring, prevention and enforcement mechanisms at EU level', European Parliamentary Research Service, https://www.europarl.europa.eu/RegData/etudes/STUD/2020/652088/EPRS_STU(2020)652088_EN.pdf

44 A. Éltető (2024), 'Why Is It Different? Specific Characteristics of the Hungarian Battery Industry: Legal Background and Environmental Impacts', HUN-REN Centre for Economic and Regional Studies, Institute of World Economics Working Paper Nr. 276, https://vgi.krtk.hu/wp-content/uploads/2024/08/Elteto_WP_276.pdf

45 M. BALLESTEROS PERALS (2025), 'Monitoring the implementation of EU law: tools and challenges', Policy Department for Citizens, Equality and Culture.Directorate-General for Citizens' Rights, Justice and Institutional Affairs, https://www.europarl.europa.eu/RegData/etudes/STUD/2025/769042/IUST_STU(2025)769042_EN.pdf

example for playing on regulatory flexibility and creating loopholes undermining harmonization.[46]

- Information asymmetry: Private firms hold more operational knowledge than regulators, especially in complex sectors like battery manufacturing. CATL leverages its global expertise to limit disclosures to the minimum required, preserving flexibility.[47]

Chapter 3

Case Study 2: A South-Korean Superstar and a would-have-been European Champion

This case study examines the strategic and operational differences between South Korea's Samsung and Sweden's Northvolt along with their broader environmental, employment and economic impacts. Europe has to narrow the technology gap over time, but it is an ongoing debate how it can most effectively support its EV and battery industry. Key questions include whether local production is sufficient for knowledge spillovers and if "localisation" under foreign ownership truly advances industrial sovereignty or merely relocates dependency. Another avenue is improving Europe's

46 M. Bildirici, Ö. Ersin, G. Olasehinde-William (2025), 'Climate Policy Uncertainty, Environmental Regulatory Arbitrage, and Internal Carbon Leakage in the European Union: Fourier ARDL and Causality Analysis', J Knowl Econ 16, 13776–13810, https://link.springer.com/article/10.1007/s13132-025-02690-0

47 A. Minto, S. Prinz & M. Wulff (2021), 'A Risk Characterization of Regulatory Arbitrage in Financial Markets', Eur Bus Org Law Rev 22, 719–752, https://link.springer.com/content/pdf/10.1007/s40804-021-00219-x.pdf

ability to sustain its own industrial champions. Exploring these completely different models for localising battery production can teach Europe valuable lessons about balancing competitiveness, sustainability, and strategic autonomy in its clean-tech transition.

The Asian and the European model. This case study examines and compares Samsung SDI's battery factory in Göd, Hungary, and Northvolt's battery factory in Skellefteå, Sweden (Figure 1). The South Korean Samsung's facility became operational in 2018, an early entry into the European battery market during a period of rapid expansion in electric vehicle adoption. Northvolt's plant began production in 2021, emerging as a European response to concerns about overdependency on Asian battery manufacturers. This difference allows for analysis of how an Asian and a European manufacturer operates in the European Union. An added complexity to the story is that in March 2025 Northvolt filed for bankruptcy. Its assets were later acquired by the US start-up Lyten, which plans to revive production at the site. This development not only underscores the volatility of Europe's battery ambitions but also raises broader questions about industrial resilience and strategic autonomy: if Europe's flagship producer falters while foreign investors take over, who ultimately commands the continent's green transition? Learning from what went wrong with one of the main symbols of Europe's clean industrial push - and from what others like Samsung have done differently - is essential in charting a viable path forward.[48]

48 R. Milne (2025), 'US battery start-up Lyten buys Northvolt out of bankruptcy', Financial Times, https://www.ft.com/content/10c55f96-5a2c-4cf0-91d2-5915380edf86

Table 1: Comparison of key characteristics of the two battery factories, 2025		
ITEM	**Samsung SDI Göd** (Hungary)	**Northvolt Ett Skellefteå** (Sweden)
Investment (EUR)	ca. €1.2 billion	ca. €15 billion
State Aid	2018: EU-approved €89.6 million[49] [50]	NA
Infrastructure Cost	2023: Gov't spent €87.4 million (HUF 34.5 bn) on waterworks[51]	NA
Capacity	40 GWh[52]	~ 32 GWh, future: up to 40–60 GWh[53]

49 European Commission (2023), 'State aid: Commission approves €89.6 million Hungarian aid', https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1265

50 J. Holman (2023), 'EC approves Eur89.6 mil Hungarian investment aid to Samsung SDI's gigafactory', S&P Global Commodity Insights, https://www.spglobal.com/commodity-insights/en/news-research/latest-news/energy-transition/022823-ec-approves-eur896-mil-hungarian-investment-aid-to-samsung-sdis-gigafactory

51 Zs. Bodnár (2025), 'Government to spend HUF 34.5 billion at Mészáros for water utility development of Samsung factory in Göd', Átlátszó, https://english.atlatszo.hu/2025/06/11/government-to-spend-huf-34-5-billion-at-meszaros-for-water-utility-development-of-samsung-factory-in-god/

52 D. Szabó (2023), 'A kormány akkumulátoripari tervei gazdasági oroszrulettté váltak, projektbedőlésekre figyelmeztetnek', Portfolio.hu, https://www.portfolio.hu/gazdasag/20230307/a-kormany-akkumulatoripari-tervei-gazdasagi-oroszrulette-valtak-projektbedolesekre-figyelmeztetnek-601152

53 A. Fyrén, S. Nordenswan (2024), 'The Hidden Costs of the Low-Emission Transition. School of Architecture and the Built Environment', KTH, https://www.diva-portal.org/smash/get/diva2:1876019/FULLTEXT01.pdf

Table 1: Comparison of key characteristics of the two battery factories, 2025		
Jobs	~ 3900 (~ 1200 new jobs)[54]	~ 5000 (2025, before bankruptcy); originally planned up to 14 000
Construction Site Type	Existing Samsung site (not greenfield)	New industrial land (greenfield)
Energy Supply	natural gas and electricity	100% renewable (hydro & wind)
Annual Power Consumption	741.66 GWh[55] [56] (electricity from the grid and on-site natural gas boilers)	384 GWh[57] (2023, from local wind- and hydropower)[58]
Daily Water Usage	~7,500 m^3/day (permit), ~3,075 m^3/day (plans)[59]	~ 1,495 m^3/day
CO_2 Emission	9.92 kg CO_2e/kWh	Target: 10 kg CO_2e/kWh

54 OECD (2023), 'Northvolt Ett – a battery cell gigafactory plant', https://www.oecd.org/en/publications/providing-local-actors-with-case-studies-evidence-and-solutions-places_eb108047-en/northvolt-ett-a-battery-cell-gigafactory-plant_83391cdc-en.html

55 Á. Kuki, C. Lakatos, L. Nagy, T. Nagy & S. Kéki (2025), 'Energy Use and Environmental Impact of Three Lithium-Ion Battery Factories with a Total Annual Capacity of 100 GWh.', Environments 12, 24, https://www.mdpi.com/2076-3298/12/1/24

56 F. Hecker (2023), 'Hivatalos: sokkal kisebb lesz a debreceni kínai akkugyár, és jóval kevesebb energiát fogyaszt majd – kiderült, mi áll a háttérben', Világgazdaság, https://www.vg.hu/cegvilag/2023/08/hivatalos-sokkal-kisebb-lesz-a-debreceni-kinai-gigaakkugyar-es-joval-kevesebb-energiat-fogyaszt-majd-kiderult-mi-all-a-hatterben

57 Nortvolt Ett (2023), 'Europe's first homegrown gigafactory', https://northvolt.com/manufacturing/ett/

58 Northvolt (2023), 'Sustainability and Annual report 2023', https://www.datocms-assets.com/38709/1719998824-northvolt_sustainability_and_annual_report_2023.pdf

59 B. Biró (2023), 'Kevesebb áramot és vizet fog fogyasztani a debreceni CATL akkugyár', Villanyautósok, https://villanyautosok.hu/2023/08/11/kevesebb-aramot-es-vizet-fog-fogyasztani-a-debreceni-catl-akkugyar/

Both companies received extensive public support from both the EU and the national governments. Samsung SDI as an established Asian multinational expanded into Europe with substantial incentives from the government of Hungary. In 2018 the EU-approved €89.6 million for the factory, while in 2023 the Hungarian government spent €87.4 million (HUF 34.5 bn) on waterworks for the plant. The plant also received €140 million of state subsidies from the government of Hungary between 2022 and 2024 for 'creating jobs'. The cumulative state aid is estimated to be €177 million covering around 15% of the total investment volume of the plant, which is €1.2 billion. Meanwhile Northvolt, a European company attempting to build domestic capacity received financing from the European Investment Bank, the EU Innovation Fund and the Commission's InvestEU programme that blends private and public funds in order to provide long term financing for sustainable recovery[60]. The total investment amount - including public and private sources - is estimated to be $15 billion.[61] Northvolt relied on coordinated European finance enabling the green transition as a young and still emerging company. Meanwhile Samsung is a mature and cash-rich company with a strong global presence that made European countries compete for its investment through privileges and sweetheart deals.

Northvolt was a greenfield investment, while Samsung expanded an already existing site. Samsung SDI's battery plant in Göd is a brownfield redevelopment, converted from a former Samsung CRT-display factory in 2016–2017. Since then, the site has undergone multiple expansion phases, reaching a production capacity of about 40 GWh annually[62]. After peaking with about 5000 employers, the factory has currently 3900 working staff,

60 EIB (2024), 'Sweden: EIB finances Northvolt's battery factory with over $1 billion', https://www.eib.org/en/press/all/2024-011-eib-finances-northvolt-s-battery-factory-with-over-usd1-billion

61 W. Martin (2025), 'An EV-battery maker that raised $15 billion from investors including Goldman Sachs filed for bankruptcy protection after almost running out of cash', Business Insider, https://www.aol.com/ev-battery-maker-raised-15-103725343.html

62 Hungarian Investment Promotion Agency (2023), 'Samsung SDI To Undertake The Largest-Ever R&D Project In HIPA History', https://hipa.hu/news/samsung-sdi-to-undertake-the-largest-ever-r-and-d-project-in-hipa-history/

still it is one of the largest employers in Pest country, a populous region just outside the capital. Though originally planned to provide jobs for about 14.000 employees, Northvolt peaked at 5000 workplaces before it went bankrupt. This figure stands in proportion with its 32 GWh annual capacity. Hence, in this respect, the two sites are quite similar. Northvolt built its battery plant as a greenfield investment, which is more taxing on the environment. However the plant's energy supply was designed more sustainably, to be fully covered from renewable sources.

The Northvolt facility run entirely on clean energy and operated with high resource efficiency. According to the environmental permit documents, water use of the Samsung SDI site is at ~7,500 m^3/day, and the plant's reported carbon intensity is 9.92 kg CO_2e per kWh of battery output. These figures make it one of Hungary's most resource-intensive industrial sites. Local environmental groups have raised concerns over the plant's water demand and the construction of related infrastructure near the Danube. In contrast the facility in Sweden was designed to have a reduced industrial water footprint. It only used 545,000 m3 water in 2023, which is less than a fifth of Samsung SDI's water consumption. Northvolt's operations were branded as highly sustainable, with production based on 100% renewable electricity (hydropower and wind)[63] and circular economy as a central element of the company's vision[64]: The Skellefteå site integrated an on-site recycling plant to recover lithium, nickel, cobalt, and other materials, aiming for 50% recycled content in cells by 2030. This positioned Northvolt as not only a major battery producer, but also a symbol of Europe's green industrial transition. At the cell level, Northvolt has achieved a carbon footprint of 33 kg CO_2e/kWh, 66% below industry benchmarks, with a roadmap to reach 10 kg CO_2e/kWh by 2030. Sustainability was embedded in product

63 Smart City Sweden (2025), 'Fossil-Free Battery Factory Accelerates Transition to Electric with 100% Green Energy, https://smartcitysweden.com/best-practice/403/fossil-free-battery-factory-accelerates-transition-to-electric-with-100-green-energy/

64 Northvolt (2022), 'A greener kind of battery factory', https://northvolt.com/articles/a-greener-factory/

development, using LCA insights to guide design choices for lithium-ion and emerging sodium-ion batteries.[65]

Samsung's Göd plant has a documented history of harmful pollution, but the Hungarian authorities seem to turn a blind eye. Samsung's Göd factory has caused significant environmental concerns since its establishment. Its water discharge contains heavy metals and solvents threatening Natura 2000 zones and nearby homes. Its airborne output quadrupled local CO_2 levels and increased the level of various air pollutants including carcinogenic NMP (N-Methyl-2-pyrrolidone). Prolonged exposure to NMP may cause miscarriage or result in abnormal fetal development. Civic organisations joining forces with investigative journalists uncovered that between 2019-2022 the factory emitted 88 tons of toxic solvent in the air.[66] Although the regulated limit of NMP emission is 2mg/m3, Samsung's operating manual worked with a 150mg/m3 limit, 75 times higher than in the regulation. The government declared the plant to be a Special Economic Zone, which allowed certain environmental permitting processes to be significantly streamlined or even completely waived. Local oversight and enforcement has also been weak. Authorities imposed minimal monitoring, and even when the company is fined, they levy only token fines of a few thousand euros, failing to deter further violations. The maximum imposable fine until 2024 was 10 000 000 HUF (~25 000 EUR), which had no meaningful deterrent effect on a company of its size.[67] Northvolt's Skellefteå facility follows ISO 14040-based life cycle assessments (LCA) and third-party audits to minimize environmental impacts. No major pollution incidents have been

65 Northvolt (2023), 'Sustainability and Annual report 2023' https://www.datocms-assets.com/38709/1719998824-northvolt_sustainability_and_annual_report_2023.pdf

66 Zs. Bodnár (2024), 'Göd battery factory: 88 tonnes of fetotoxic solvents in the air, heavy metals in workers' immune systems', Átlátszó, https://english.atlatszo.hu/2024/02/27/god-battery-factory-88-tonnes-of-fetotoxic-solvents-in-the-air-heavy-metals-in-workers-immune-systems/

67 Göd-ÉRT Egyesület (2023), 'Mi a baj a gödi Samsunggal – és a többi akkugyárral?', https://drive.google.com/file/d/1dV-sc6Kdcrz8tQIK8AvVgg49PWKAmX7c/view?usp=drive_link&usp=embed_facebook

reported, minor spills and emissions were swiftly contained in line with Swedish and EU regulations.

Samsung has been in a constant battle with the local community, while residents in Skellefteå held an overwhelmingly positive attitude towards the Northvolt plant. Residents and local authorities recognized Northvolt as a major driver of economic and social revitalization in the region. Since the factory's development started, Northvolt has significantly boosted the local economy[68]. A November 2022 survey found that only 4.5% of Skellefteå's community viewed Northvolt's presence as detrimental to their municipality, while over 75% held a positive attitude. Northvolt engaged in various local development projects to help meet the growing demands of the plant including plans of new housing, and the establishment of education programs geared towards upskilling and reskilling.[69] Samsung meanwhile encountered opposition from local residents, particularly during the expansion of its factory in Göd. The decision was conducted without public consultation and locals only learned about the massive industrial investment through the media. Transparency was absent: in case of fires or emergencies neither residents nor Göd's mayor received any information, even when they draw large-scale first-responder efforts[70]. Locals formed the Göd-ÉRT Association to further their cause fighting for more transparency, safety and public discourse. Despite repeated requests from the association,

68 OECD (2023), 'Northvolt Ett – a battery cell gigafactory plant. Places case study library', https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/04/providing-local-actors-with-case-studies-evidence-and-solutions-places_20b385f4/northvolt-ett-a-battery-cell-gigafactory-plant_e3d7e0fe/83391cdc-en.pdf

69 OECD (2023), 'Northvolt ETT - A BATTERY CELL GIGAFACTORY PLANT', https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/04/providing-local-actors-with-case-studies-evidence-and-solutions-places_20b385f4/northvolt-ett-a-battery-cell-gigafactory-plant_e3d7e0fe/83391cdc-en.pdf

70 Göd-ÉRT Egyesület (2023), 'Mi a baj a gödi Samsunggal – és a többi akkugyárral?', https://drive.google.com/file/d/1dV-sc6Kdcrz8tQIK8AvVgg49PWKAmX7c/view?usp=drive_link&usp=embed_facebook

decision-makers from the government and the company refused to engage with the community, except for the legally required public hearings, which were treated as mere formalities[71]. This pattern continued throughout the factory's eight expansion phases, until the eventual establishment of a special economic zone. This status exempts the plant from Hungarian laws including consultation requirements with the local community, while it also removes any legal avenue for municipalities to obstruct the plans. Looking at Hungary's rapid, low-transparency approach and Sweden's deliberative, high-compliance model reflects Europe's dilemma between competing with China in the short run or maintaining its environmental and social standards.

Samsung's Göd plant received operating permits despite workers' safety falling short of EU standards. Samsung's Göd plant has experienced fatal workplace accidents and still lacks real-time safety monitoring. Despite years of violations such as ongoing operations in unlicensed sections, unsafe hazardous-materials storage or ignored safety standards, the factory kept receiving permits to operate. For instance, one report found that there was no main power shut off switch, which is essential to save lives and mitigate damage in case of fire. According to investigations in 2021 the air in the plant contained 10 and 20 times the regulated maximum levels of nickel and cobalt endangering the health of workers.[72] Similarly to breaches related to pollution, the company only received minor fines up to 10 million HUF until 2024. In 2024, a government decree increased the maximum fine for endangering workers to 100 million HUF (250 000 EUR)[73]. Since then

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71 Göd-ÉRT Egyesület (2024), 'Nem működhetne a Samsung – de mégis megteszi', https://www.godert.hu/nem-mukodhetne-a-samsung-de-megis-megteszi/

72 Zs. Bodnár (2024), 'Göd battery factory: 88 tonnes of fetotoxic solvents in the air, heavy metals in workers' immune systems', Átlátszó, https://english.atlatszo.hu/2024/02/27/god-battery-factory-88-tonnes-of-fetotoxic-solvents-in-the-air-heavy-metals-in-workers-immune-systems/

73 A. Bánáti (2025), '100 millióra büntették a gödi akkugyárat, negyedjére bírságolták őket a dolgozók veszélyeztetése miatt', telex, https://telex.hu/gazdasag/2025/07/02/samsung-godi-akkugyar-dolgozok-sulyos-veszelyeztetese-100-millio-forint-birsag

Samsung was already fined for this maximum amount. Northvolt meanwhile enforced a company-wide Health, Safety, and Environment (HSE) roadmap with clear responsibilities at every level, mandatory worker-led hazard reporting, and unified standards shared across all sites. Full-time union safety representatives and robust occupational health services support its proactive safety culture. Despite these measures, two fatal incidents occurred at Northvolt in 2023; production was halted and only resumed after protocols were reviewed and reinforced[74].

Both plants attracted an international workforce, but Northvolt provided much higher job quality. Half of Samsung's workers in Göd are Hungarian, while the other half originates mainly from Ukraine, Korea and Vietnam.[75] Samsung has faced controversies related to reliance on foreign labor and poor working conditions. Workers live in overcrowded accommodations nearby, often as many as thirty to forty people sharing a single house. This causes issues with the local residents fueled by the Hungarian government's anti-migrant propaganda[76]. Northvolt had 5,800+ employees with multi-disciplinary expertise from 116 countries, around half of whom were Swedish. The company used marketing and talent attraction programs to encourage relocation and recruitment of skilled professionals. It also encouraged women to join its workforce to create an inclusive workplace and match their goal of 40% (they reached 28% in 2023). Housing was also an issue for Northvolt as 800 people lived at Camp Ursviken in a series of temporary

74 Northvolt (2023), 'Sustainability and Annual report 2023', https://www.datocms-assets.com/38709/1719998824-northvolt_sustainability_and_annual_report_2023.pdf

75 Zs. Tamásné Szabó (2021), 'Rengeteg ukrán munkahelyét „védi" a kormány a gödi Samsung-gyárban, ahol helyiek alig dolgoznak', 24.hu, https://24.hu/fn/gazdasag/2021/11/26/samsung-sdi-god-gyar-dolgozoi-letszam/

76 Göd-ÉRT Egyesület (2023), 'Mi a baj a gödi Samsunggal – és a többi akkugyárral?', https://drive.google.com/file/d/1dV-sc6Kdcrz8tQIK8AvVgg49PWKAmX7c/view?usp=drive_link&usp=embed_facebook

modular homes[77]. The company invested in housing developments and new plans to provide sustainable solutions to the issue. Furthermore, Northvolt invested in education programs and an in-house battery science academy to upskill and motivate existing talent. After bankruptcy, laid-off Northvolt workers received various forms of support. The Swedish government has established dedicated service centers in Västerås and Skellefteå to assist former Northvolt employees. Union members[78], particularly those belonging to Sveriges Ingenjörer and IF Metall, received comprehensive support such as relocation compensation, tips on available jobs and financial support for studies.[79] [80] [81]

Samsung's plant does not bring meaningful technological spillover to the EU, while Northvolt spearheaded innovation. Northvolt's approach represented the most comprehensive attempt by any European company to develop battery innovation capabilities and intellectual property. Northvolt's strategy focused on next-generation battery technologies (like sodium-ion batteries) that could provide European manufacturers with competitive advantages over established Asian producers. Despite the company's eventual bankruptcy, its technological development activities established

77 A. Fahlgren (2024), 'Northvolt workers critical of accommodation conditions', Radio Sweden, https://www.sverigesradio.se/artikel/northvolt-workers-critical-of-accommodation-conditions

78 akademikernasakassa.se (2025), 'Members of Sveriges Ingenjörer: Engineers to receive support following Northvolt bankruptcy', https://www.akademikernasakassa.se/om-oss/aktuellt/nyheter/2025/mars/members-of-sveriges-ingenjorer-engineers-to-receive-support-following-northvolt-bankruptcy

79 Arbetsförmedlingen (2025), 'Swedish Public Employment Services: Support if you have been let go from Northvolt', https://arbetsformedlingen.se/for-arbetssokande/tips-inspiration-och-nyheter/artiklar/2025-05-23-support-if-you-have-been-let-go-from-northvolt

80 Statens servicecenter (2025), 'Affected by Northvolt', https://www.statenssc.se/en/affected-by-northvolt

81 IF Metall (2025), 'Information for IF Metall members at Northvolt', https://www.ifmetall.se/aktuellt/information-till-if-metalls-medlemmar-pa-northvolt/information-for-if-metall-members-at-northvolt/

important foundations for European battery technology and demonstrated both the potential and challenges of building technological sovereignty in strategic industries.[82] Samsung's R&D center in Göd, opened in 2025, focusing primarily on process optimization rather than advancements in battery technology. The facility is one of Samsung's five global R&D centers, but its role is largely confined to adapting existing technologies to European production requirements and optimizing manufacturing processes for local conditions. Workers had less R&D intensive jobs with on average lower value-added. This approach provides minimal contribution to European technological sovereignty, as there is limited transfer of knowledge and expertise. The core intellectual property and innovation capabilities remain concentrated in Samsung's Asian operations.[83] Samsung's limited knowledge transfer and Northvolt's ambitious but financially troubled R&D strategy reveals Europe's unresolved dilemma between attracting foreign capital and building domestic capacity. The failure of Northvolt raises uncomfortable questions about whether Europe can realistically achieve battery sovereignty, or whether a hybrid model accepting foreign manufacturers under stricter technology-sharing terms may be necessary.

Both companies had a hard time economically in the past years, but only Samsung stayed afloat. Market demand for electric vehicles in Europe slowed down, because the transition from fossil fuel cars to electric ones isn't happening as quickly as expected. This has reduced battery demand and forced automakers to reconsider their electrification strategies. Samsung experienced a challenging year in 2024[84], and reported a €58.5 million loss; due to slowdown in demand and revenue. The majority of the factory's output was exported to the parent company, while only a small share was sold in the European Union and the United Kingdom. Under such

82 Northvolt Patents (2025), 'Key Insights & Stats', https://insights.greyb.com/northvolt-patents/

83 P. Kovács (2025), 'Átadták a Samsung SDI új központját Gödön, ahol a gyártási folyamatot fogják fejleszteni', telex, https://telex.hu/gazdasag/2025/06/11/szijjarto-peter-samsung-god-kutatas-fejlesztes-beruhazas

84 F.I. Vitéz (2025), 'Akkumulátorgyárak: veszteség és leépítés, amerre a szem ellát', 24.hu, https://24.hu/fn/gazdasag/2025/06/05/samsung-sdi-god-akkumulatorgyarak-veszteseg-leepites-veszelyes-hulladek/

strain Samsung's Göd operations received substantial state subsidies from Hungary amounting to €140 million between 2022 and 2024. By contrast despite being more environmentally friendly, sustainable and bringing more added value to the European economy, Northvolt filed for bankruptcy in 2025. Northvolt faced severe financial, logistical and technical challenges[85] including high capital costs, and supply chain disruptions[86]. Even leadership challenges emerged after the chairman stepped down for health reasons, weakening investor confidence. The company failed to scale up production at its Skellefteå gigafactory, achieving only 1 GWh instead of the targeted 16 GWh. BMW's cancellation of a $2 billion contract in June 2024 was a major blow. Despite raising over $14 billion altogether, rising costs and lack of new investment made sustaining operations difficult leading to bankruptcy. Although the company ceased production in spring 2025, the US-based battery firm Lyten acquired the remaining assets and is planning to restart production in 2026[87].

Europe has to narrow the technology gap over time, but it is an ongoing debate how it can most effectively support its EV and battery industry. These contrasting outcomes illustrate the complexity of Europe's green industrial transition. While Samsung's model delivered operational continuity and cost competitiveness, it did so at the expense of environmental integrity, community trust, and technological autonomy. Northvolt's approach embodied European sustainability values and innovation ambitions but ultimately could not overcome market pressures and operational challenges. The failure - in some aspects - of both models suggests that Europe must develop a new framework that integrates rigorous environmental governance with industrial viability, balancing foreign investment with

85 S. Tagliapietra, C. Trasi (2024), 'Northvolt's struggles: a cautionary tale for the EU Clean Industrial Deal', Bruegel, https://www.bruegel.org/analysis/northvolts-struggles-cautionary-tale-eu-clean-industrial-deal

86 L, J (2025), 'Northvolt's Bankruptcy: How Does It Impact Europe's Battery Industry?' Carbon Credits, https://carboncredits.com/northvolts-bankruptcy-how-does-it-impact-europes-battery-industry/

87 Laio (2025), 'US firm Lyten buys bankrupt Northvolt, eyes 2026 restart', https://ioplus.nl/en/posts/us-firm-lyten-buys-bankrupt-northvolt-eyes-2026-restart

domestic capacity building to achieve genuine strategic autonomy in the battery sector. The production of batteries within EU borders does not result in automatic technological spillover or clean production. At the same time sustaining European industrial champions in the field is difficult even with state support due to cost competitiveness issues, pressured market dynamics and the strength of competitor companies. Exploring these cases can teach Europe valuable lessons about balancing competitiveness, sustainability, and strategic autonomy in its clean-tech transition.

- Technological spillover: Northvolt's strategy focused on next-generation battery technologies that could provide European manufacturers with competitive advantage. Meanwhile Samsung's R&D center in Göd focused primarily on process optimization, while the core intellectual property and innovation capabilities remain in its Asian operations.
- Resource intensity: The Samsung SDI site is one of Hungary's most resource-intensive industrial sites, while Northvolt's operations were highly sustainable, with production based on 100% renewable electricity.
- Toxic pollution: Samsung's Göd factory has a documented history of harmful pollution since its establishment. At the Northvolt site no major pollution incidents have been reported, minor spills and emissions were swiftly contained in line with Swedish and EU regulations.
- Relations with local community: Residents and local authorities recognized Northvolt as a major driver of economic and social revitalization in the region, while Samsung has been in a constant battle with the local community.
- Workers safety: Samsung's Göd plant received operating permits despite workers' safety falling short of EU standards. Northvolt enforced a company-wide Health, Safety, and Environment (HSE) roadmap with unified standards shared across all sites.
- Product costs: Samsung managed to produce at lower costs partly due to social and environmental dumping. BMW's cancellation of its major contract with Northvolt was partly due to price reasons amidst the slowing demand.

- Regulatory environment: The Hungarian government created a permissive environment for Samsung, while Sweden held up EU standards.
- Maturity and strength of the company: Samsung's parent company absorbed majority of the produced output during the global slowdown of the industry and sheltered the battery producing arm from insolvency. Meanwhile Northvolt was a young and still emerging company without established links to automotive companies.
- State support: Both companies received extensive state support. Northvolt relied on coordinated European finance enabling the green transition as a young and still emerging company. Meanwhile Samsung is a mature and cash-rich company with a strong global presence that made European countries compete for its investment through privileges and sweetheart deals.

Chapter 4

Outlook - Key Factors that will Shape the Future of the Industry

Europe's drive to build domestic battery production capacity has become a strategic imperative amid shifting geopolitical dynamics. However the global EV and battery market is entering a period of uncertainty and transformation driven by market consolidation, geopolitical tensions, potential regulatory changes and technological disruption. Signs of these are already visible. Production of EV batteries far outpaces demand leading to low profitability and bankruptcies. China imposed export controls on various rare earth elements and products in 2025 as a retaliation to US tariffs. Germany's current chancellor Mr Merz looks keen to lift the accepted EU ban on new cars with internal combustion engines from 2035. Advanced recovery methods can already produce battery-grade lithium approaching cost parity with traditional mining operations[88]. For Europe to find the right EV and battery strategy and the appropriate policies it is essential to examine the industry's outlook and likely future dynamics.

Weaker than expected demand for EVs and oversupply causes intense consolidation in the battery market. The global battery industry, after years of remarkable expansion, has encountered a slowdown in late 2024. Although total battery demand across all applications - including electric vehicles, grid-scale energy storage, and consumer electronics - crossed the historic 1 terawatt-hour (TWh) threshold for the first time in 2024 (1 TWh of electricity can fully power 70,000 homes for a year[89]), it fell short of its previously expected growth trajectory. The industry has been characterised by oversupply, intensifying competition [90]and falling prices. Battery prices dropped by an average of 20% in 2024, with Chinese manufacturers experiencing 30% price drops compared to 10-15% in Europe and the United States. Chinese companies are likely involved in a price-war to hog market shares. Few make profits, while BYD was months behind on payments to suppliers in 2025 August.[91] Other major battery suppliers like LG Energy Solutions or Samsung SDI reported weaker quarterly results and losses, while

88 J. Zadeh (2025), 'Latest Technologies for Recovering Lithium from EV Batteries', Discovery Alert, https://discoveryalert.com.au/news/lithium-recovery-ev-batteries-2025-economic-environmental-importance/

89 Global Macro Monitor (2024), 'AI's Impact On Energy Demand', https://global-macro-monitor.com/2024/06/21/ais-impact-on-energy-demand/

90 R. Berger (2025), 'Global battery market continues to see strong growth despite uncertainties and holds opportunities for European manufacturers', Mynewsdesk https://www.mynewsdesk.com/rolandberger/pressreleases/global-battery-market-continues-to-see-strong-growth-despite-uncertainties-and-holds-opportunities-for-european-manufacturers-3368422

91 The Economist (2024), 'China's manufacturers are going broke' https://www.economist.com/business/2024/08/08/chinas-manufacturers-are-going-broke?gclsrc=aw.ds&gad_source=5&gad_campaignid=23069926051&gclid=EAIaIQobChMItYXsjL-3kAMVGBeiAx3aZTeZEAAYASAAEgL6mPD_BwE

Northvolt, Europe's battery champion went bankrupt[92 93]. This consolidation trend is expected to intensify through 2030 as more producers are likely to fail before demand bounces back[94]. In this environment it is difficult for a new European battery champion to emerge and stay afloat without strategic or targeted support. The German carmaking industry itself is forecasted to lose almost 20%, 140 000 workers by 2035 due to the transition to electric vehicles, which require less manpower to build and face more competition from China.[95]

Resource needs will soar beyond current mining capacity in the near future. The period between 2025 and 2040 will likely witness unprecedented growth in demand for rare earth minerals and other materials needed for battery production.[96] By 2040, global demand for lithium, nickel, and graphite, is projected to increase by 14, 20, and 19 times, respectively compared to 2020 levels[97]. Demand solely for metals used in batteries such as lithium, copper and aluminium is forecasted to quadruple by 2040 reaching 53

92 C. Randall (2025), 'IEA report: Dimensions and trends of the global battery market', https://www.electrive.com/2025/06/03/iea-report-dimensions-and-trends-of-the-global-battery-market/

93 BloombergNEF (2024), 'EV Slowdown Countered by Energy Storage Boom' https://about.bnef.com/insights/clean-transport/ev-slowdown-countered-by-energy-storage-boom/

94 BloombergNEF (2024), 'China Already Makes as Many Batteries as the Entire World Wants', https://about.bnef.com/insights/clean-transport/china-already-makes-as-many-batteries-as-the-entire-world-wants/

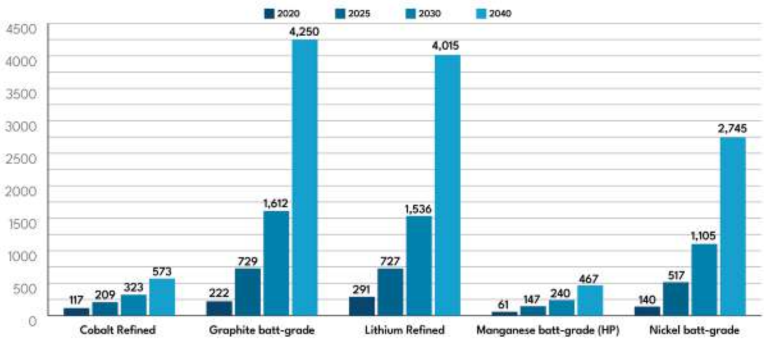
95 E. Sigfried (2024), 'Employment in the automotive industry: Prognos study shows profound change process through transformation', VDA, https://www.vda.de/en/press/press-releases/2024/241029_Prognos_study_on_regarding_Employment_in_the_automotive_industry

96 J. Zadeh (2025), 'Latest Technologies for Recovering Lithium from EV Batteries', Discovery Alert, https://discoveryalert.com.au/news/lithium-recovery-ev-batteries-2025-economic-environmental-importance/

97 European Comission (2025), 'RMIS - Lithium-based batteries supply chain challenges.' https://rmis.jrc.ec.europa.eu/analysis-of-supply-chain-challenges-49b749

million tons[98]. This projected increase far outpaces production and mining capacity including planned developments. Resource needs are expected to peak during the mid-2030s straining global mining and processing capacity as well as supply chains. An added geopolitical complexity is that in 2024 China had a near monopoly on the supply of cathode (85%) and anode materials (90%), which are key for producing batteries.[99] Amidst shortages and geopolitical tensions it is questionable how the EU will ensure resource needs for domestic battery production.

Figure 5: Forecast of global battery demand globally from processed raw



Source: JRC analysis https://rmis.jrc.ec.europa.eu/analysis-of-supply-chain-challenges-49b749

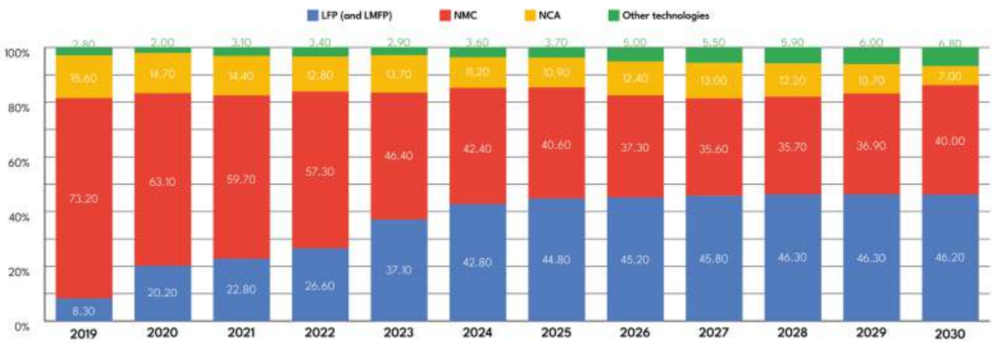
Advancements in recycling could cover half of the EU's demand in certain raw materials for battery production. The transformation toward a circular economy is one of the most significant industrial transitions of the next two decades. It is expected to create new industries and reshape existing supply chains around principles of sustainability and resource security. Recycling technologies will achieve unprecedented recovery rates over the next decade as circular business models emerge to maximize value

98 The Oregon Group (2025), 'Battery metals demand set to quadruple by 2040', https://theoregongroup.com/commodities/copper/battery-metals-demand-set-to-quadruple-by-2040/

99 IEA (2025), 'Global EV Outlook 2025, Electric Vehicle Batteries' https://www.iea.org/reports/global-ev-outlook-2025/electric-vehicle-batteries

extraction from battery lifecycles. Direct recycling methods will enable reuse of materials at higher aggregation levels, making recycling more cost-effective and sustainable. By 2034, battery recycling will evolve from a waste management necessity into a strategic material supply industry worth nearly $100 billion[100]. This process is also enhanced by stringent EU regulations. The EU Battery Regulation sets out ambitious targets: 50% lithium recovery by 2027 rising to 80% by 2031, while cobalt, copper, and nickel must achieve 90% recovery by 2027 and 95% by 2030. By 2031, batteries must contain minimum proportions of recycled materials: 16% cobalt, 6% lithium, and 6% nickel. As a result by 2030, Europe will face the need to collect and recycle over one million tonnes of batteries, with the European recycling market expected to reach €15 billion within five years.[101]

Figure 6: Composition of batteries in electric cars
by technology over time (2019-2030, %)



Note: NCA – Nickel Cobalt Aluminum; NCM – Nickel Cobalt Manganese; L(M)FP – Lithium (Manganese) Iron Phospate; Other technologies include solide state, sodium-ion and Mn rich batteries. Data for 2024-2030 are based on previous market forecasts.
Source: https://www.goldmansachs.com/insights/articles/electric-vehicle-battery-prices-are-expected-to-fall-almost-50-percent-by-2025

100 Future Trends in Li-Ion Battery Recycling for 2025 and Beyond - Green Li-ion. https://www.greenli-ion.com/post/future-trends-in-li-ion-battery-recycling-for-2025-and-beyond

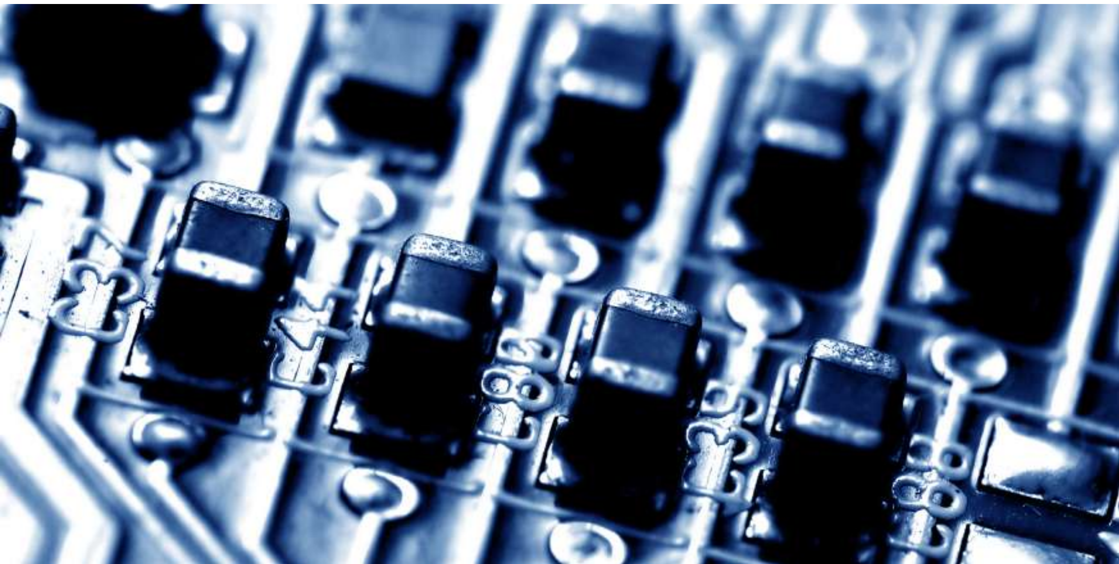
101 ACC (2025), 'PLUGGED IN #1 - Battery recycling: Supporting and organising circularity' https://www.acc-emotion.com/stories/plugged-1-battery-recycling-supporting-and-organising-circularity

Recycling could contribute up to 51% of cobalt and 42% of nickel demand of the EU by 2040.[102]

Next generation battery technology will bring down costs and reliance on rare-earth minerals. The global battery industry is facing a fundamental technological transformation over the next 15 years, characterized by diversification toward multiple competing technologies. Commercial battery chemistries are rapidly evolving, driven by market demands, improved cathode materials and electrification of transport. Lithium iron phosphate (LFP/LMFP) will experience substantial growth, expanding from approximately 8% market share in 2019 to 46,2% by 2030, driven by its cost advantages, safety profile, and improving energy density performance[103]. The EU could consider investing in these more efficient technologies to increase its cost competitiveness and further bring down reliance on the long and tricky supply chain of rare-earth minerals.

102 European Comission (2025), 'RMIS - Lithium-based batteries supply chain challenges.' https://rmis.jrc.ec.europa.eu/analysis-of-supply-chain-challenges-49b749

103 Goldman Sachs (2024), 'Electric vehicle battery prices are expected to fall almost 50% by 2026' https://www.goldmansachs.com/insights/articles/electric-vehicle-battery-prices-are-expected-to-fall-almost-50-percent-by-2025



Next generation battery technology - more efficient, affordable, durable and safe

Sodium-ion batteries (SIBs) operate on the same basic principle as lithium-ion cells, but substitute sodium (Na^+) ions for lithium (Li^+) ions in both electrodes and the electrolyte. Sodium-ion technology is particularly promising for stationary energy storage, where cost and safety outweigh the need for maximum energy density (stored energy/battery weight) meaning batteries can be larger and heavier. It can also serve as a backup for grid balancing and renewable integration. Recent pilot production by companies like CATL and Faradion suggests commercial modules could reach the market in the mid-2020s

Solid-state batteries offer higher energy density, faster charging and improved safety compared to today's lithium-ion cells, due to the nonflammable electrolyte, and longer cycle life. In these batteries the liquid or gel electrolyte in the lithium-ion cells is replaced with a solid electrolyte - often ceramic, glass, or polymer. This solid electrolyte conducts lithium ions between the anode and cathode with greater electrochemical stability. Many designs also use lithium-metal anode instead of graphite, boosting energy density, while the solid electrolyte serves as a physical barrier against dendrite formation preventing short-circuit. However, solid-state batteries face hurdles such as lower efficiency at room-temperature and high manufacturing costs. Key potential applications of such batteries include electric vehicles (with extended range), grid storage (due to higher durability), and portable electronics (due to its compactness and safety). Pilot production of these batteries by major automakers and startups are expected for the late 2020s, with widespread market adoption likely in the early 2030s once cost and scale challenges are overcome[104] [105] [106] [107].

104 A. More (2025), 'Silicon Anode Battery Market US Tariff Impact CAGR of 41.7%', https://www.news.market.us/silicon-anode-battery-market-news/

105 T. Kavanagh (2023), 'Next-gen batteries could dominate Europe by 2040', Latest Market News, https://www.argusmedia.com/en/news-and-insights/latest-market-news/2493093-next-gen-batteries-could-dominate-europe-by-2040 (2023)

106 Amprius (2025), 'Understanding New Battery Tech for Electric Vehicles', https://amprius.com/new-ev-battery-tech/

107 JJ. Marie, S. Gifford (2023), 'The Faraday Institution. Developments in Lithium-Ion Battery Cathodes', Faraday Insights - Issue 18, https://www.faraday.ac.uk/wp-content/uploads/2023/09/Faraday_Insights_18_FINAL.pdf

Innovations in manufacturing of batteries will improve safety, efficiency and reduce adverse environmental impact. Battery manufacturing is an industry that uses materials that are harmful for the environment as well as human health. Currently it requires workers to manipulate toxic materials and the treatment of the waste is complex and costly. The European Battery 2030+ initiative sets out for the industry to shift towards chemistry-neutral approaches to mitigate this impact. It also encourages the development of autonomous "self-driving" laboratories that combine artificial intelligence, machine learning and high-throughput automated synthesis to limit human exposure and accelerate the manufacturing process. High-throughput automated synthesis is able to test thousands of material compositions simultaneously with the help of robotics, artificial intelligence, and parallel experimentation. Enhanced thermal management systems will also be incorporated into 95% of lithium-ion batteries by 2030 to prevent fires and improve safety, while self-healing battery functionalities will enable autonomous restoration of degraded components through passive and active mechanisms triggered by external stimuli[108 109 110].

A key disclaimer: the battery industry's trajectory through 2040 will depend critically on climate policy commitments. The European Climate Law targets climate neutrality by 2050, with at least 55% emission reductions by 2030 (compared to levels in 1990) and a proposed 90% by 2040. This positions batteries to deliver part of the required decarbonization

108 Store.Frost.com (2025), 'Safety Innovations in Lithium-ion Battery Tech 2025–2030', https://store.frost.com/safety-innovations-in-lithium-ion-battery-technology-growth-opportunities-2025-2030.html

109 B. Tran (2025), 'The Future of Battery Technology: 2030 Market Predictions and Energy Storage Innovations', PatentPC, https://patentpc.com/blog/the-future-of-battery-technology-2030-market-predictions-and-energy-storage-innovations

110 K. Edström (2023), 'Inventing the sustainable batteries for the future – Research needs and future actions', https://battery2030.eu/wp-content/uploads/2023/09/B-2030-Science-Innovation-Roadmap-updated-August-2023.pdf

in transport and power sectors.[111] However, growing political willingness to weaken climate targets creates fundamental uncertainty for demand projections. The German Chancellor suggested that the policy to ban new car sales with internal combustion engines in 2035 was wrong, while the US already rolled back subsidies for electric cars. Recent EU decisions to soften automotive CO_2 compliance through three-year averaging and to accelerate the review of the 2035 combustion ban could further reduce EV sales and hence battery demand. Since industry forecasts assume consistent progression toward net-zero to 2050, any policy rollback would trigger a fall in projected EV demand and along the supply.

A summary of the projected market dynamics between 2025-2040 based on the trends outlined above, assuming current climate policy commitments;

- **2025-2030: Further increase in geographic and industry concentration.** Global battery production could reach a capacity of 7,9 TWh by the end of 2025, which is five times the projected demand. The most probable near-term scenario involves further consolidation of the China-centric battery ecosystem due to competitive pressures. China is in a strategic position in the supply chain of materials needed for battery production. It aims to increase its planned production capacity to 6 TWh, which could meet total global battery demand by 2035. This would further force smaller and less established players to exit, while strengthening the position of leading manufacturers like CATL, BYD, and EVE Energy[112]. Trade wars and escalating geopolitical tensions might hamper access to Chinese controlled rare earth materials and products. This creates a challenging environment for non-Chinese manufacturers to enter the market or compete in the near future.

111 European Commission (2023), 'European Climate Law', https://climate.ec.europa.eu/eu-action/european-climate-law_en#documentation

112 M. Reid (2025), 'China's overcapacity: Will its battery industry consolidate?', CRU Group. CRU Group Website, https://www.crugroup.com/en/communities/thought-leadership/2025/chinas-overcapacity-will-its-battery-industry-consolidate/

- **2030-2035: Resource needs peak, while technology reshapes the industry.** Resource needs are expected to peak during the mid-2030s[113] with China controlling 80-90% of certain materials and their processing. Global supply chains will increasingly shorten and regionalize along geopolitical lines. Trade barriers will likely continue to force Chinese manufacturers to establish production facilities in key markets such as the EU or Canada to maintain access. Meanwhile technological advancements continue to improve manufacturing and battery efficiency. Advances in next-generation battery technologies promise both cost reductions and enhanced supply-chain resilience, while innovations in manufacturing are poised to boost safety and reduce the environmental footprint of production. Solid-state batteries for example are expected to begin commercialization after 2030, initially targeting premium EV

113 European Comission (2025), 'RMIS - Lithium-based batteries supply chain challenges.' https://rmis.jrc.ec.europa.eu/analysis-of-supply-chain-challenges-49b749

segments[114]. By the mid 2030s battery recycling will evolve from a waste management necessity into a strategic material supply industry worth nearly $100 billion[115]. New types of batteries and battery recycling technologies can create an opportunity for Japanese and European manufacturers to compete on technology rather than cost[116].

- **2035-2040: The industry matures bringing more balanced regional market shares.** By 2040, the battery industry is likely to evolve into a mature market with established regional champions. Global battery demand is projected to reach 9,1 TWh by 2035, finally absorbing current overcapacity and potentially creating supply constraints in certain segments[117] [118]. As regional production increases China's market share of EV batteries will decline to 50%, however Chinese manufacturers will maintain technological leadership in key segments[119]. Resource needs will continue to soar, but recycling will become a major industry segment, satisfying up to 50% of the EU's demand in certain critical raw materials by 2040. Recycling in its own will become a major industry segment, with global battery recycling capacity potentially reaching 157

114 Mordor Intelligence (2025), 'EV Solid-state Battery Market Size, Trends & Forecast Report, 2030', https://www.mordorintelligence.com/industry-reports/ev-solid-state-battery-market

115 Green Li-ion (2025), 'Future Trends in Li-Ion Battery Recycling for 2025 and Beyond', https://www.greenli-ion.com/post/future-trends-in-li-ion-battery-recycling-for-2025-and-beyond

116 International Lithium Association (2025), 'Lithium 2040: The element shaping our future. Project Blue', https://lithium.org/wp-content/uploads/2025/05/ILiA-and-Project-Blue-Lithium-The-element-shaping-our-future.pdf

117 IEA (2025), 'Critical Minerals Data Explorer – Data Tools', https://www.iea.org/data-and-statistics/data-tools/critical-minerals-data-explorer

118 World Economic Forum (2025), 'Powering the future: Overcoming Battery Supply Chain Challenges with Circularity', https://reports.weforum.org/docs/WEF_Powering_the_Future_2025.pdf

119 electrive.com (2025), 'IEA report: Dimensions and trends of the global battery market', https://www.electrive.com/2025/06/03/iea-report-dimensions-and-trends-of-the-global-battery-market/

billion in investment by 2040 up from 26 billion in 2030[120].

Europe has to find the right EV and battery strategy amidst market consolidation, geopolitical tensions, regulatory changes and technological disruption. Europe faces a complex challenge as the global EV and battery market is entering a period of transformation and uncertainty. The European car industry is of strategic importance in terms of both jobs and GDP. Electrification is a key field, where important advances will be the source of a competitive advantage in the near future. Europe has to narrow the technology gap over time, but its battery ambitions also hinge on a fragile balance between industrial acceleration and regulatory integrity. A larger European battery industry could catalyze job creation across manufacturing, research & development, and downstream services. Beyond electric vehicles, a diversified battery ecosystem has potential applications such as light electric vehicles, renewable energy storages, and consumer electronics. Europe could also be a global leader in recycling technologies and transformation toward a circular economy. By aligning strategic investment, technological innovation, and environmental safeguards, the EU can transform its battery ambitions into a driver of sustainable growth and technological sovereignty.

120 Charted: Investment Needed to Meet Battery Demand by 2040. Elements by Visual Capitalist (2024) https://elements.visualcapitalist.com/investment-battery-demand-by-2040/

Chapter 5

Local Factories, Foreign Control: Strategic Autonomy and Value Chains in the EU's Battery Rollout

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Senior Researcher, Max Planck Institute for the Study of Societies

The EU's battery manufacturing rollout is expanding rapidly, but much of the new capacity is foreign-owned, with high value-added activities, innovation, and control remaining offshore—limiting Europe's technological sovereignty. Ironically, efforts to localize battery production and reduce China-dependence have triggered a surge of Chinese ownership in the sector, with little attention to securing domestic spillovers. This policy brief examines the gap between localization and genuine strategic autonomy, drawing on a project-level dataset and five country case studies. It shows how

Without shifting from "any capacity, anywhere" to conditional, coordinated, champion-oriented investment, Europe risks building an industry whose critical decision-making levers remain outside its grasp, undermining the very sovereignty these investments are meant to secure.

current EU and national policies prioritize rapid capacity build-out through foreign direct investment—over domestic value capture and technological control. The analysis concludes with three policy recommendations: conditional openness to foreign investment, coordinated EU-level governance of subsidies, and sustained support for domestic champions, aiming to shift the focus from headline capacity figures to real control over the value chain.

1. Introduction: Local Factories, Foreign Control

In 2022, European Commission Vice President Maroš Šefčovič addressed the annual conference of the Hungarian Battery Alliance, a government-affiliated business platform. He praised Hungary as the sector's "pioneer" and "a European battery champion" helping "achieving strategic autonomy in this critical sector"—"all the more important following Russia's unjustified invasion of Ukraine." Yet Hungary's battery pipeline rests on foreign, increasingly Chinese-owned firms, is powered by Russian fossil fuels, and concentrated in the hands of an autocratic government with ties to Beijing and Moscow. For most observers, this was a bizarre foundation for EU "strategic autonomy." If the bloc's sovereignty in a critical sector rests on such a configuration, what does "strategic autonomy" even mean?

This paradox is not an isolated anomaly but a symptom of a deeper structural problem. The EU's battery strategy bundles three objectives—climate neutrality, industrial competitiveness, and strategic autonomy—without clear prioritisation or binding definitions. In practice, this allows localization to stand in for autonomy, even when value chains, ownership structures, and geopolitical alignments remain unchanged.

Batteries are a key enabling technology of the green transition. Securing this capability is not simply about safeguarding automotive supply chains—it is about anchoring a cornerstone of Europe's future energy system. Yet technological sovereignty depends on control over the knowledge and innovation that underpin production. Europe will not gain that knowledge merely by localizing assembly; without deeper capabilities in high-value segments, local plants risk becoming little more than foreign-owned outposts.

Drawing on a dataset of EU gigafactory projects and five country vignettes, this brief examines whether the EU's localisation drive enhances sovereignty or merely shifts dependency—and outlines a path forward for more genuine autonomy.

2. Strategic Autonomy: Concept and Value-Chain Logic

In EU industrial policy, strategic autonomy has become shorthand for resilience, sovereignty, and competitiveness.[1] In batteries, it signals the ability to secure green technologies without being beholden to foreign suppliers.[2] The appeal is clear: Europe can decarbonize, reindustrialize, and hedge against geopolitical shocks in one move.

But the concept is elastic. It can mean reducing import dependence, localizing production, building domestic champions, or aligning with trusted partners. These aims overlap but can conflict. A plant may be localized yet foreign-owned. An EU firm may still depend on imported inputs. Without clear priorities, almost any localization can be branded as strategic autonomy—even when real control remains abroad.

This brief focuses on cell manufacturing—the anchor investment that locks in downstream vehicle production and much of the value added.

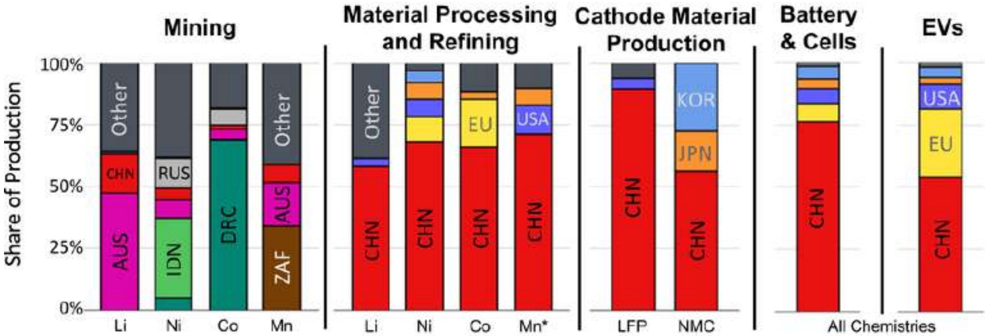
Upstream vulnerabilities nonetheless shape what "autonomy" at the cell level can deliver. As Figure 1 shows, China's dominance is not confined to one stage of the chain—it spans almost all of it. Chinese firms control the majority of global refining for lithium, nickel, cobalt, and manganese, near-total dominance in cathode material production, and the largest single share of cell manufacturing. Even if Europe localizes cell assembly,

1 Luuk Schmitz and Timo Seidl, "As Open as Possible, as Autonomous as Necessary: Understanding the Rise of Open Strategic Autonomy in EU Trade Policy," JCMS: Journal of Common Market Studies 61, no. 3 (2023): 834–852.

2 The concept resonates with influential works on "weaponized interdependence", see: Henry Farrell and Abraham L. Newman, "Weaponized Interdependence: How Global Economic Networks Shape State Coercion," International Security 44, no. 1 (2019): 42–79.

dependence on Chinese-processed inputs leaves the industry exposed to supply disruptions and foreign standard-setting.

Figure 1: Geographical distribution of the EV battery supply chain.[3]



The EU's Critical Raw Materials Act (CRMA)[4] sets domestic targets for extraction, processing, and recycling. But mining projects face fierce opposition—Serbia's planned Jadar mine has already been suspended. These tensions illustrate a deeper dilemma: reducing foreign dependence can heighten local environmental and social tensions.[5]

The CRMA addresses part of Europe's upstream exposure, but raw material security alone will not determine strategic autonomy. In practice, the EU's industrial policy tools and investment flows have concentrated far more on cell manufacturing — the stage that anchors downstream vehicle production, captures significant value added, and shapes the geography

3 Source: Anthony L. Cheng, Erica R. H. Fuchs, Valerie J. Karplus, and Jeremy J. Michalek, "Electric Vehicle Battery Chemistry Affects Supply-Chain Disruption Vulnerabilities," Nature Communications 15, no. 2143 (March 8, 2024): 2.

4 European Parliament and Council of the European Union. Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials. http://data.europa.eu/eli/reg/2024/1252/2024-05-03.

5 Pálma Polyák, "Sacrifice Zones: The Local Costs of the Electric Vehicle Investment Boom in Hungary and Serbia" (conference paper, 2025 Annual Meeting of the Society for the Advancement of Socio-Economics, 2025).

of automotive supply chains. It is here, rather than in mining or refining, that member states have exercised the most discretion in structuring projects and setting conditions.

Within this core segment, two contrasting strategies have emerged. The minimalist path prioritizes rapid capacity build-out via foreign direct investment, often without conditions on technology transfer or local integration. It delivers quick jobs and headline capacity but leaves governance and technology in foreign hands. The maximalist path seeks to anchor domestic firms, impose spillover requirements on foreign investors, and integrate production with local supply chains. Slower, more expensive, and riskier, it offers the only route to genuine autonomy at the cell level.

Why Autonomy Requires Upgrading

Strategic autonomy and domestic upgrading are inseparable. Without capturing high-value segments—design, IP, process technology—local plants remain dependent on foreign decision-making. In a geopolitical crisis, proximity offers little leverage if production lines and contracts are controlled abroad.

The Hungarian case illustrates the risk: even with the largest battery pipeline in the EU, its plants could not be easily repurposed for alternative customers in a supply disruption scenario, as critical inputs and engineering processes are tied to foreign parent companies. Conversely, France's domestically anchored project pipeline shows the opposite logic: a smaller, slower rollout anchored in state-linked "domestic champions" creates a platform for future autonomy—though at high fiscal and execution risk.

Policy Contradictions

EU-level industrial instruments, like the Important Projects of Common European Interest (IPCEI), target high-value segments and R&D. But loosened state-aid rules since 2020 have allowed member states to subsidise mass production directly, with little coordination.[6] This benefits

6 Donato Di Carlo, Dimitri Zurstrassen, and Andreas Eisl, "Together We Trade, Divided We Aid: Mapping the Flexibilization of the EU State Aid Regime across GBER, IPCEIs and Temporary Frameworks," Joint JDI–LUHNIP Policy Paper 307 (November 2024), https://doi.org/10.13140/RG.2.2.28572.71040.

minimalist strategies, as foreign firms play states off each other.

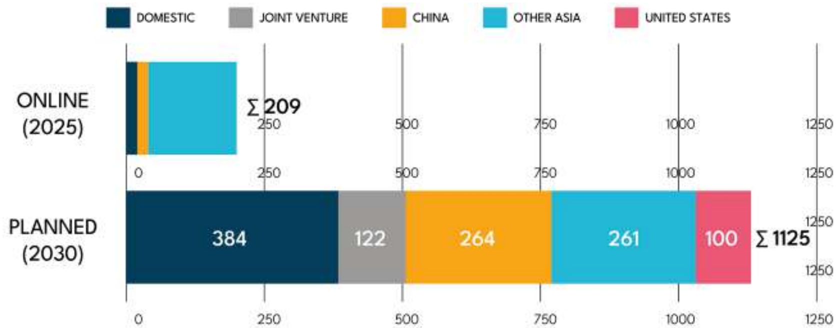
The result is structural incoherence: the EU funds both domestic champions and their foreign rivals in the same market. It's akin to nurturing an infant industry while inviting global incumbents to set up next door with public backing.

3. State of Play: EU-Level Trends and Country Cases

By 2024, the EU hosted 209 GWh of operational battery cell manufacturing capacity, concentrated in just five member states: Poland, Hungary, Germany, France, and—before Northvolt's bankruptcy—Sweden. The installed base is dominated by Korean-headquartered firms (LG Energy Solution, Samsung SDI, SK On), with CATL's Erfurt plant marking Chinese presence. European producers make up only a small share of production.

By 2030, planned capacity will increase fivefold, to over 1,125 GWh (Figure 2)—enough to equip the EU's current car output with 80 kWh batteries.[7]

Figure 2: Planned and operational EU battery manufacturing capacities by company headquarters (GWh/year; planned: maximum capacities)[8]



7 Average Battery Capacity (kWh) of Available BEV Models per Year. Data: European Commission

8 Source: Author's compilation of project-level data. Includes operational and announced battery cell manufacturing projects in the EU27, coded by location, nominal capacity, company headquarters, project status, and direct fiscal support. Risk profiles are assigned based on project-specific indicators such as financing, offtake agreements, permitting, and parent company viability.

Despite the headline growth, more than 65 percent of planned 2030 capacity is expected to be controlled by non-European firms. Chinese companies—either directly (CATL, AESC, EVE) or through joint ventures (CATL/Stellantis, Gotion/InoBat)—hold the largest single share. In stark contrast to the United States, where Foreign Entity of Concern (FEOC) provisions exclude Chinese firms from federal subsidies and where political pushback spans from local activists to federal lawmakers, the EU has rejected this emerging "Cold War II" framing.

European firms such as ACC and Verkor (headquartered in France), or PowerCo (Germany), as well as some smaller projects, together make up roughly one-third of the pipeline—an improvement, but still insufficient to shift the balance of control.

Planned capacities are highly volatile, with projects frequently downsized or cancelled. Between 2018 and 2024, 356 GWh—about a quarter of the EU investment pipeline—was abandoned. While 85 percent of operational capacity is foreign-owned, 86 percent of cancellations involved domestic projects.

The aggregate figures also mask how closely battery production trajectories are tied to Europe's largest automakers, who control demand and hedge their bets across suppliers. The "European champions" still standing—Verkor, ACC, PowerCo—are all anchored by OEMs with close state ties and even ownership stakes: Renault, Stellantis (via Peugeot), Volkswagen. These political linkages support long-term offtake and patient investment. Even so, hedging is common: Volkswagen has taken a controlling stake in Chinese producer Gotion while developing its own PowerCo plants. By contrast, BMW and Mercedes-Benz—both without state shareholders—have mostly bypassed European champions entirely. BMW exited a €2 billion Northvolt contract, sealing the fate of the company, and pivoted to East Asian producers in Hungary; Mercedes relies on CATL contracts (despite holding a minority stake in ACC), leaving it without domestically anchored supply. These choices shape national strategies and mostly reinforce foreign dominance. The following country vignettes trace how these dynamics play out in practice.

Hungary – Scale Without Sovereignty

Hungary has the EU's largest national battery pipeline, accounting for over one-fifth of planned production capacity by 2030. This expansion is almost entirely foreign-led: Korean firms (Samsung SDI, SK On) operate existing plants, while Chinese firms (CATL, EVE, Sunwoda) lead upcoming projects. Political ties to Beijing and Moscow, combined with dependence on Russian fossil fuels, create vulnerabilities that undercut EU goals. The sector is energy and water-intensive, with lax oversight and growing public opposition. Despite headline capacity, Hungary's model delivers little domestic upgrading—technology and engineering remain foreign-controlled. Regulatory forbearance and severe ecological and labor rights violations make it the clearest minimalist-path example. [9]

Germany – Industrial Powerhouse, Foreign Anchors

Germany combines industrial strength with deep foreign reliance. Volkswagen's PowerCo plants aim to build domestic capacity, but major supply contracts still rely on foreign producers—most notably CATL's Erfurt plant, developed without tech-transfer conditions. This echoes Germany's prior overexposure to Russian gas: assuming commerce trumps geopolitics. Germany hosts the most IPCEI battery projects and invests in upstream innovation. Its strong industrial base could support future upgrading. Yet foreign firms still dominate installed cell capacity, and Germany lacks local content requirements. Even an industrial leader struggles to align localization with autonomy.

Poland – Geopolitical Hawk, No Domestic Grip

Poland's cell manufacturing base is dominated by LG Energy Solution, the Korean producer operating Europe's largest gigafactory in Wrocław. Warsaw increasingly views Chinese FDI through a security lens, and has largely avoided Chinese investment at the cell level, reflecting close alignment with

9 Andrea Éltető, Why Is It Different? Specific Characteristics of the Hungarian Battery Industry: Legal Background and Environmental Impacts, IWE Working Papers 276 (Budapest: Institute for World Economics – Centre for Economic and Regional Studies, August 2024).

the United States in its broader foreign policy posture. Yet Chinese firms are present in upstream segments such as cathode active materials and electrolytes, showing that exclusion is functionally impossible. Importantly, without domestic firms, Poland's battery sector remains entirely foreign-controlled, limiting its ability to translate geopolitical caution into industrial sovereignty. The result is a geopolitically shaped value chain that still delivers little long-term upgrading.

France – Conditional Openness

France has pursued the clearest form of a developmental strategy, including a more deliberate mix of domestic and foreign-led investment. Its largest foreign-backed cell plant, ProLogium's Dunkirk facility, comes from Taiwan rather than China and is tied to €1.5 billion in state aid with technology-sharing commitments. Also generously subsidised, French headquartered champions ACC and Verkor anchor the "Battery Valley" cluster in Hauts-de-France, linked to reindustrialization and job creation in a region marked by deindustrialization. While Chinese investment is not excluded—Envision/AESC is in the pipeline—it is balanced with domestic capacity and tied to supply-chain integration and workforce development. This maximalist-leaning approach trades speed for greater potential in value capture and supply security. However, the fiscal costs involved in this strategy are mounting, and France's domestic champions still have not reached commercial viability.

Sweden – A Cautionary Tale

Sweden's battery strategy revolved around Northvolt, celebrated as Europe's flagship homegrown producer. Its bankruptcy in 2024, after chronic financing shortfalls and production delays, underscored how vulnerable European champions are in a market dominated by deep-pocketed Asian incumbents (propped up by subsidies in a single market). Sweden retains strong R&D capacity and abundant renewable energy, but the collapse leaves a gap in domestic production and a cautionary lesson: autonomy at the cell level requires patient capital, secure offtake agreements, and resilience to market downturns—not just technological ambition.

Overall, the EU's cell manufacturing rollout shows rapid localization without equivalent gains in control. In most cases, ownership, engineering, and upstream inputs remain concentrated in foreign hands. Without a shift toward maximalist elements—domestic champions, conditional FDI, and deeper supply-chain integration—Europe's battery capacity risks becoming an impressive but hollow asset.

4. Policy Directions: Navigating Trade-Offs in Strategic Autonomy

While the EU talks a great deal about strategic autonomy, its approach to batteries remains strikingly inattentive to the geopolitical dimensions of supply chains. Capacity figures dominate the narrative, while questions of ownership, technology control, and political leverage receive far less weight. Yet Europe cannot and should not aim for autarky; the sector is deeply embedded in global value chains, and foreign investment—Chinese included—will remain part of the picture. China's technological dominance is overwhelming, and it is naive to expect rapid change. The challenge is to accept interdependence but govern it deliberately—shaping foreign participation to deliver upgrading, innovation, and resilience, rather than locking in dependency.

Conditional Openness

Foreign direct investment, including from Chinese producers, can help accelerate capacity build-out and secure supply for EU firms. But without conditions, it risks locking Europe into low-value roles. Public support—subsidies, infrastructure, or permitting—should be contingent on measurable spillovers: tech transfer, R&D co-location, supplier integration, and workforce training. Deep-pocketed incumbents can decline grants if they dislike the terms, so conditionality must be embedded in broader project approvals—not just tied to subsidies.

EU-Level Governance of Subsidies

Since 2020, loosened state-aid rules have created a subsidy landscape where member states compete to attract large projects, often with weak or absent conditions. This race to the bottom entrenches incoherence: EU states fund both domestic firms and foreign incumbents. A coordinated EU-level framework should set minimum conditionality standards, prioritize upgrading over sheer capacity, and target gaps across the value chain. Aligning national incentives with shared goals will reduce duplication and ensure public funds enhance, rather than dilute, sovereignty.

Backing Domestic Champions

Northvolt's collapse showed how fragile European producers are in a market dominated by cash-rich East Asian rivals. Supporting champions requires more than startup grants—it takes patient capital, guaranteed demand, and political backing. EU institutions and national governments should consider equity stakes, low-interest loans, and offtake guarantees for strategically important firms. Support must also extend beyond gigafactories to domestic firms across the value chain, where technological spillovers and ecosystem effects are strongest.

5. From Capacity to Control

The EU must enforce its own rules to manage political, environmental, and social risks. Rule-of-law conditionality must apply consistently, including to autocratic member states whose governance undermines strategic goals. As Kelemen and Pavone have shown, the Commission's reluctance to act—even amid violations—weakens the credibility of EU objectives.[10] Environmental and labor standards must be enforced uniformly to avoid a race to the bottom in safeguards.

These measures won't eliminate foreign reliance, but they can ensure localization delivers more than impressive gigawatt-hour figures. Strategic autonomy in battery cell manufacturing is about control over technology, supply, and upgrading—not just where factories are located. Without a shift from "any capacity, anywhere" to conditional, coordinated, champion-oriented investment, Europe risks building an industry whose critical levers remain outside its grasp.

10 R. Daniel Kelemen and Tommaso Pavone, "Where Have the Guardians Gone? Law Enforcement and the Politics of Supranational Forbearance in the European Union," World Politics 75, no. 4 (2023): 779–825.

Chapter 6

Environmental Protection: The Hidden Costs of European Battery Manufacturing

Gergely Simon
Chemical Expert

One of the central narratives of Europe's green transition is electromobility. Both Brussels policymakers and EU strategists emphasize that replacing fossil fuels with electric vehicles (EVs) enables the European Union to meet its ambitious climate goals while reducing energy dependence on imported oil and gas. Electromobility is therefore not only a technological shift in transportation but also an industrial and geopolitical project: the EU aims to redefine its position in global supply chains.

> It is unacceptable that local residents are left unaware of which toxic substances are being handled only 100 meters from their homes, or what impacts these may have on them.

While electric vehicles can significantly reduce greenhouse gas emissions from the transport sector, their production – especially battery manufacturing – carries significant environmental burdens due to the raw materials required. Battery production generates ecological costs in two main dimensions: first, through raw material extraction, typically occurring in ecologically sensitive and politically unstable regions of the Global South; second, through the operation of large battery factories, which places significant pressure on local water resources due to its enormous water demand, while also polluting soil and air, and consuming substantial amounts of energy.

This chapter examines the environmental consequences of the rise of the European battery industry. It highlights Greenpeace's recent research on the impacts of lithium, cobalt, nickel, and manganese extraction and explores how environmental conflicts emerge in the EU's eastern periphery, particularly in Hungary.

1. Global Impacts of Raw Material Extraction

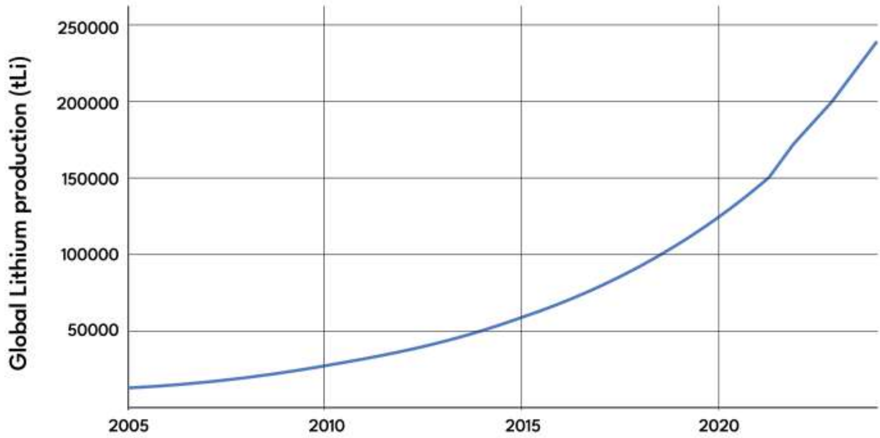
Lithium-ion battery cathodes can vary but are usually composed of lithium compounds combined with other metals. In the automotive sector, and in factories in Hungary and Europe, the most common cathode type is NMC (lithium-nickel-manganese-cobalt oxide, $LiNiMnCoO_2$). Lithium-cobalt-oxide ($LiCoO_2$) is used in phones and laptops, while Tesla batteries often use lithium-nickel-cobalt-aluminium ($LiNiCoAlO_2$). In China, lithium iron phosphate ($LiFePO_4$) cathodes are increasingly used for EVs, avoiding hard-to-source metals but offering lower capacity. Anodes are usually made of graphite.

Modern EV lithium-ion batteries therefore require large quantities of four minerals: lithium, cobalt, nickel, and manganese. Their extraction and processing carry multiple environmental risks. Greenpeace's 2025 report, Charging Toward Zero Emissions[1], details the ecological and social damages caused by the production of these raw materials. The so-called 'green transition' thus paradoxically brings not sustainability, but new environmental injustices for those living in the Global South.

1 Charging Toward Zero Emissions. How to Ensure a Fair and Sustainable Battery Supply Chain. Greenpeace East Asia, 2025 https://www.greenpeace.org/static/planet4-eastasia-stateless/2025/07/306a9bac-charging-toward-zero-emissions_final_en.pdf

Global demand for lithium surged nearly 30% in 2024—compared to the previous decade's 10% annual growth—while demand for nickel, cobalt, and graphite grew 6–8%, primarily due to battery production.[2]

Figure: 1 - Global Lithium production (t Li) - Year



Source: Lithium production. Our World in Data https://ourworldindata.org/grapher/lithium-production

Lithium: Water Scarcity and Ecosystem Damage

The symbolic site of lithium extraction is the South American "Lithium Triangle," encompassing the salt flats of Chile, Argentina, and Bolivia. Today, over 80% of all lithium produced is used in batteries, and this share could rise to as much as 95% by 2030.

Lithium is extracted using evaporation-based technologies, which require enormous amounts of water. Mining brine from these salt flats severely damages geodiversity—that is, the diversity of geology, soils, and landforms. Geodiversity, in turn, underpins biodiversity by supporting ecosystem resilience. Through this pathway, lithium mining indirectly threatens biological diversity and ecological stability.

2 IEA - Global Critical Minerals Outlook 2025 https://www.iea.org/reports/global-critical-minerals-outlook-2025/executive-summary

In the desert region of the Salar de Atacama, lithium extraction has already been shown to contribute to declining groundwater levels, soil desertification, and the disruption of traditional agricultural practices such as quinoa cultivation and livestock rearing. Lithium mining depletes freshwater resources, especially in evaporation-based extraction, where a significant portion of water is lost to evaporation. This process endangers local agricultural activities, the livelihoods of Indigenous communities, and both food and water security. Water extraction is particularly problematic in regions where precipitation is already extremely low.[3] [4]

Cobalt: Pollution and Human Rights Violations

The Democratic Republic of Congo (DRC) is the center of cobalt mining, supplying up to 80% of global cobalt in 2024[5]. Mining here causes severe environmental damage—deforestation, soil and water pollution—as well as serious human rights abuses. Numerous international reports, including Amnesty International's, document child labor without protective equipment and extremely hazardous working conditions[6].

According to a report by Earth.org,[7] cobalt mining in the DRC causes severe environmental and health problems. Toxic waste and acidic effluents from the mines pollute local rivers, damaging fish populations and soil ecosystems, thereby reducing soil fertility. Furthermore, the air in mining areas is dust-laden and toxic, leading to respiratory illnesses and

3 Sovacool, B. et al. (2020): "Sustainable Minerals and Metals for a Low-Carbon Future. Science, 367(6473)

4 Rentier, E. S. (2024). Lithium brine mining affects geodiversity and Sustainable Development Goals. Renewable and Sustainable Energy Reviews, 202, 114642. https://doi.org/10.1016/j.rser.2024.114642

5 "Global Cobalt Supply to Surpass 300kt Mark in 2024, Driven by Production from the DRC and Indonesia." Mining Technology, 17 Jan. 2025, https://www.mining-technology.com/analyst-comment/global-cobalt-supply-2024/

6 Amnesty International (2019): This is What We Die For: Human Rights Abuses in the Democratic Republic of the Congo Power the Global Trade in Cobalt. https://www.amnesty.org/en/documents/afr62/3183/2016/en/

7 Charlotte Davey: The Environmental Impacts of Cobalt Mining in Congo, Mar 28th 20234 https://earth.org/cobalt-mining-in-congo

an increased incidence of birth defects. Deforestation linked to mining further exacerbates biodiversity loss. Urine sample analyses conducted among residents of the Katanga region revealed that people—particularly children—living near cobalt mines showed significantly elevated levels of cobalt, cadmium, lead, and uranium. Cobalt concentrations were among the highest ever recorded in a general population worldwide.[8]

Nickel: Deforestation and Water Pollution

Nickel mining in Indonesia and the Philippines is associated with large-scale deforestation and the pollution of valuable aquatic ecosystems. According to Greenpeace, the by-products generated during nickel processing—particularly acidic mine drainage—contaminate local rivers and coastal marine habitats. This environmental degradation places the livelihoods of local fishing communities at serious risk.

A Greenpeace Indonesia report[9] highlights that the Raja Ampat archipelago, often referred to as the "Last Paradise on Earth," faces severe threats from nickel mining. Sixteen mining permits have been issued across the archipelago, 12 of which are located within the UNESCO Global Geopark area. Several permits that were previously revoked or had expired have since been reissued. Nickel mines and the associated steel smelters impose significant environmental burdens, endangering biodiversity, local communities, and the tourism sector alike.

Manganese: Environmental and Health Risks

Manganese mining carries serious environmental and health risks. Waste and sediment generated during mining contaminate water and soil with heavy metals, reducing biodiversity, while land disruption and deforestation

8 Nkulu Banza, C. L., Nawrot, T. S., Haufroid, V., Decrée, S., De Putter, T., Smolders, E., Ilunga Kabyla, B., Luboya, O. N., Ilunga, A. N., Mwanza Mutombo, A., & Nemery, B. (2009). High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo. Environmental Research, 109(6), 745–752. https://doi.org/10.1016/j.envres.2009.04.012

9 Paradise Lost? How nickel mining threatens the future of one of the world's most important biodiversity hotspots, Greenpeace Indonesia, 2025

lead to habitat destruction. In addition, inhalation of manganese dust and consumption of contaminated water can cause long-term neurological problems and toxic effects in local communities. Research conducted around the Dubna manganese mine in India[10] found that high levels of manganese in soil and water were linked to health issues among nearby populations. The accumulation of manganese and other heavy metals also resulted in observable symptoms of chronic poisoning among residents.

2. Environmental Risks of European Battery Factories

While the global impacts of raw material extraction are primarily felt in the Global South, European battery factories also create local environmental conflicts. The EU aims to develop domestic production capacity to reduce dependence on China, with Hungary emerging as a hub in Debrecen, Komárom, and Göd through large investments by South Korean and Chinese companies. Greenpeace Hungary and investigative portal [Átlátszó][11] [12] have repeatedly highlighted the environmental and social risks of these facilities.

10 Goswami, S., et al. (2009). Environmental impact of manganese mining: A case study of Dubna opencast mine, Keonjhar District, Orissa, India. Journal of Ecophysiology and Occupational Health, 9(3), 189–197.

11 What are the environmental concerns associated with battery factories in Hungary? Greenpeace Hungary (2025)

12 Battery factories articles, at Átlátszó

Water and Energy Use

Battery giga factories are extremely water-intensive, consuming tens of millions of liters daily—comparable to the needs of a city of 100,000–200,000 residents. In drought-prone areas like Debrecen, communities fear groundwater depletion, threatening agriculture and drinking water. Under current Hungarian permits, these facilities are not required to recycle or reuse their wastewater.

Battery factories are also highly energy-intensive. Planned Hungarian production capacity could reach 250 GWh/year by 2030, requiring 15–16 TWh annually—roughly the output of four Paks nuclear blocks. The exact ratio of electricity to heat energy is still unknown, but most of the heat for battery production is likely to come from natural gas. Since the energy demand was not taken into account in the relevant strategic documents, it remains unclear how the government plans to ensure the necessary supply and to what extent this will increase the country's carbon dioxide emissions.

Chemicals and Workplace Accidents

The construction and operation of battery factories involve serious workplace and health risks, which can lead to poisoning and other illnesses. Battery production requires the use of numerous hazardous and toxic chemicals that, when released into the environment, can harm both wildlife and human health. These risks persist throughout the lifetime of the factory. One such substance is NMP, a reproductive toxin that can harm foetuses and is regulated under EU law, meaning it can only be used under strict conditions. Both the cathode and the electrolyte contain several toxic chemicals.

Despite regulatory interventions and fines, problems often persist, and workers remain exposed to toxic substances. Numerous examples can be found in Hungary. For instance, during the construction of the Iváncsa battery plant, one worker was poisoned, and accidents resulted in 14 additional injuries and three deaths, while the authorities only issued warnings and minor fines. Several accidents have also occurred during the operation of the Iváncsa plant, such as an electrolyte leak that caused multiple workers to fall ill.

At the Samsung SDI factory in Göd, tests repeatedly showed that employees' bodies contained carcinogenic heavy metals (such as nickel and cobalt) at levels several times higher than the permitted limits. In 2025, Átlátszó reported that Samsung was fined hundreds of millions of forints for failing to carry out mandatory biological monitoring for carcinogenic heavy metals, including nickel and cobalt, in the case of 66 employees, thereby seriously endangering their health. According to the 2025 article, over the past few years, the factory had to pay a total of 378 million forints in fines due to unlawful operations.[13]

Environmental Pollution

Greenpeace and its partners frequently observe that cases of environmental pollution are not properly investigated by the authorities. For example, in 2022, N-Methyl-2-pyrrolidone (NMP), a solvent can be harmful to foetuses, was detected in wells in Göd, yet no explanation has ever been provided by the authorities as to how the substance entered the water. Similarly, in February 2024, when municipal sewage spilled onto agricultural land near the Samsung SDI plant, Greenpeace measured an NMP concentration of 200 micrograms per litre in groundwater. Authorities, however, failed to explain how the chemical reached the soil.

Within just one year, over 80 tonnes of NMP were released into the air from the Göd factory, with the cause and impacts still unclear. Residents living near the Komárom battery plant regularly report foul odours, and on several occasions workers have also been exposed to harmful substances

13 Hungarian articles from the media: https://24.hu/fn/gazdasag/2023/12/02/ivancsai-akkugyarepites-3-halott-1-mergezes-14-serult-1-figyelmeztetes-42-millio-forint-birsag/

https://telex.hu/belfold/2024/04/10/ivancsai-akkumulatorgyar-rosszul-lettek-a-dolgozok

https://atlatszo.hu/orszagszerte/2025/07/02/szazmillios-birsagot-kapott-a-godi-akkugyar-dolgozoi-sulyos-veszelyeztetese-miatt/

through inhalation.[14]

Risks of Scrap and Waste Processing

One of the major risks of battery manufacturing is the handling of defective and waste batteries, as well as the large volumes of faulty cells produced during manufacturing. In the early stages of production, the defect rate in factories can be as high as 40 percent, resulting in significant quantities of hazardous waste. The variable composition of electrolytes and the presence of unknown compounds further increase the risks of processing.

In Hungary, this waste currently undergoes only preliminary treatment (such as discharging and shredding), while final recycling mostly takes place in Asia. During processing, workers are exposed to fire and explosion hazards, as well as toxic substances such as nickel, cobalt, and lithium compounds and substances of the electrolyte, all of which may be carcinogenic and harmful to health.

In Hungary battery recycling plants have already reported fatal accidents and cases of environmental pollution, highlighting the serious occupational and health challenges posed by waste management and defect processing. For instance, carcinogenic nickel was detected in the bodies of employees at the Bátonyterenye recycling plant.[15]

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14 Hungarian articles: https://atlatszo.hu/kozugy/2022/05/26/nem-derult-ki-hogyan-kerult-mergezo-oldoszer-a-kutvizbe-lakossagi-forum-godon/

https://www.greenpeace.org/hungary/sajtokozlemeny/11078/a-greenpeace-a-godi-kommunalis-szennyvizben-talalt-akkumulatorgyartashoz-hasznalt-magzatkarosito-oldoszert/

https://atlatszo.hu/orszagszerte/2024/02/20/godi-akkugyar-88-tonnanyi-magzatkarosito-oldoszer-a-levegoben-nehezfemek-a-dolgozok-szervezeteben/

https://hvg.hu/kkv/20240401_sk-komarom-akkumulatorgyar-baleset-szuros-szag

15 Hungarian articles: https://atlatszo.hu/orszagszerte/2023/07/28/nem-egy-hanem-ket-ember-halalat-okozta-egy-geprobbanas-a-szigetszentmiklosi-akku-feldolgozoban/ https://telex.hu/gazdasag/2025/05/28/batonyterenyei-akkufeldolgozo-sungeel-dolgozok-laborvizsgalat-nikkel

Greenfield Investments, Social TEnsions and Democratic Deficit

Almost all battery industry projects in Hungary are implemented as greenfield investments. The CATL giga-project in Debrecen is also being realized in this form, which means that 220 hectares of high-quality arable land will be permanently withdrawn from agricultural production. Such decisions, taken systematically, can weaken the country's food security in the long term, while inflicting irreversible damage on soil, one of Hungary's most valuable natural resources. Brownfield investments, by contrast, would offer the opportunity to reuse land that has already been utilized for industrial or military purposes, thereby avoiding the sacrifice of fertile agricultural areas. For the local population, the Debrecen project has also generated social tensions, as the community was only involved after the decision had already been made. In Hungary, the Iváncsa factory was likewise built as a greenfield investment, just as the plant in Göd, located directly next to the settlement. Since the Samsung battery manufacturing facilities were established in Göd, the town has been struggling with increased traffic, noise pollution, and occasional foul odors emanating from the factory area.

According to Greenpeace, Hungarian environmental authorities often appear to protect corporations from local communities, workers, and civil society, rather than protecting residents and the environment from polluters.

The cases in Hungary clearly illustrate the problem of "environmental injustice": while the benefits of electromobility—such as reduced urban pollution—are primarily enjoyed by urban, higher-income consumers, rural communities living near the factories bear the environmental risks. Approval processes are often expedited and provide minimal opportunities for local input. This issue can therefore be understood not only as an environmental problem but also as a matter of democratic accountability.

All this highlights that the development of the battery industry can only be sustainable if the government prioritizes brownfield investments and engages in genuine social dialogue with local communities.

Political Framework and EU Regulation

Within the framework of the Green Deal and the Fit for 55 package, the

European Union has set ambitious goals for promoting e-mobility. The Critical Raw Materials Act[16], adopted in 2023, aims to diversify raw material supplies and strengthen circular solutions. Nevertheless, the fundamental contradiction remains: regardless of their source, raw material extraction always entails ecological damage.

Currently, there is no unified EU regulation on battery manufacturing in force. The Industrial Emissions Directive (IED) did not cover battery production until the summer of 2024. The directive must be incorporated into national law within two years (by July 1, 2026); however, the development of the Best Available Techniques (BAT) reference document (BREF) under the IED could take up to four years. This document will outline the specific technologies to be applied and the permissible environmental emissions for battery manufacturing facilities. Until a harmonized EU-wide BREF/BAT is established, it will be up to the national EU authorities to determine the details of the permits within the relatively broad EU framework.

In March 2025, the European Commission accepted [17]that lithium battery waste and its recycling byproduct —black mass—should be classified as hazardous waste under the European Waste Catalogue (EWC). This change will come into effect in a year and a half, meaning that until autumn 2026, it will still be possible in Hungary to store and handle battery waste and its byproducts as non-hazardous.

EU regulations also include recycling targets (such as for the recovery of lithium, cobalt, and nickel), but in practice, implementation often falls short of ambition. According to Greenpeace, real change will only come if the EU makes the use of recycled materials in battery manufacturing mandatory.

16 European Commission (2023): Critical Raw Materials Act. https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en

17 New battery-related waste codes will boost circular management of batteries and their critical raw materials, 5 March 2025, Directorate-General for Environment https://environment.ec.europa.eu/news/battery-related-waste-codes-update-set-boost-circular-economy-2025-03-05_en

3. Solutions

Regulation, Transparency and Safer Chemicals

EU institutions must require full supply chain transparency—from documenting the environmental impacts of mining to publishing manufacturers' carbon footprints. Greenpeace emphasizes that so-called "no-go zones," such as primary forests or water protection areas, must enjoy special protection.[18] At the EU level, environmental limit values should be established for hazardous substances used in lithium-ion battery production (for example, regarding groundwater and surface waters), and these substances should also be taken into account when classifying hazardous installations under the Seveso Directive. At present, however, some of the particularly hazardous chemicals applied in production (such as NMP) are not covered by the Seveso Directive. As a result, no threshold values are defined for them, and certain battery factories are therefore not officially categorized as hazardous facilities. The EU regulation within the REACH framework, which requires the substitution of hazardous substances with safer alternatives, should be enforced much more rigorously. In the case of battery plants, safer materials and technologies do exist, and their application should be much more strongly promoted both by EU rules and by national authorities.

Brownfield Investments

Instead of greenfield developments, brownfield projects should primarily be authorized worldwide, as these do not endanger fertile soils. Numerous contaminated areas, left behind by earlier industrial activities, are awaiting remediation and reuse, and could provide suitable sites for such facilities. In particular, battery production plants should only be established on brownfield sites, at a safe distance from residential areas.

18 Minerals for Energy Transition: Greenpeace's Guiding Principles, Greenpeace International (2025) https://www.greenpeace.org/international/publication/75188/minerals-for-energy-transition-greenpeaces-guiding-principles/

Public Participation

The involvement of local communities in battery factory permitting procedures is essential. The Aarhus Convention—ratified by the EU—guarantees citizens the right to access environmental information, participate in decision-making, and seek legal remedy. In practice, however, these requirements are often not met.

It is unacceptable that local residents are left unaware of which toxic substances are being handled only 100 meters from their homes, or what impacts these may have on them. The chemicals used, emissions released, and the fate of battery waste—including both manufacturing waste and defective products—must be made publicly known. It is equally unacceptable that in Hungary, battery waste containing numerous hazardous substances is still treated as non-hazardous.

It is also unacceptable that the Hungarian government designates certain projects as nationally significant investments, thereby simplifying the permitting process, shortening environmental approval procedures, and making independent, science-based impact assessments more difficult. Moreover, it is essential to involve local communities and civil society organizations before any decisions are made. No meaningful decisions on such large-scale investments should be taken without the support of the local population.

Rethinking Mobility

Although phasing out internal combustion vehicles and meeting climate goals requires electric cars (and batteries), the overall number of cars on the road must be reduced. This can be achieved through investments in affordable public transport powered by renewable energy, the promotion of cycling and walking, and reducing dependence on private vehicles.

Meanwhile, cities must be designed so that all essential services are within easy reach, avoiding the need for private car use. Where driving is necessary, alternatives such as car-sharing should be available, as they also help reduce the number of private vehicles and thereby mitigate raw material demand.

Chapter 7

Technology, Industry and Competitiveness: Balancing Ambition with Reality in Europe's Battery Push

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Europe's claim to the battery age is no accident. In Italy, Alessandro Volta's voltaic pile in 1800 and, a few decades later, the Hungarian priest–physicist Ányos Jedlik's compact motor and model electric vehicle are early chapters in a long European story of electrification. Those inventions now read like a prologue to a much larger unfolding story: batteries are at the very heart of the clean-transport transition and the EU's Green Deal ambitions, and global commitments from Conference of the Parties (COP 28) point to rapidly rising

> Europe's success will depend on its ability to marry strategic intervention with market-driven innovation, ensuring that its battery ecosystem becomes not just a protected venture, but a genuinely competitive and resilient pillar of its future economic and environmental security.

demand.[1] According to the International Energy Agency (IEA), batteries are today "the fastest growing energy technology in the market", global battery storage doubled in 2023 while EV battery deployment jumped by about 40%.[2] Yet the modern industry also reveals a strategic paradox: supply chains remain highly concentrated, with China accounting for roughly 85% of cell production. Europe's historical pedigree sits alongside hard, contemporary choices about how (and whether) to rebuild competitive capacity at scale.

This chapter will assess Europe's battery push through a balanced lens, examining its industrial strengths, internal constraints, external opportunities, and mounting geopolitical risks. It will also explore the portrayal of the battery industry as a cornerstone of future competitiveness and technological leadership. Are these expectations realistic and sustainable in the long term, and is large-scale investment in battery manufacturing the most effective industrial strategy for Europe?

1. EU Policy Framework and Strategy

The EU regulatory framework' seeks to combine several distinct but interconnected policy tools and strategies towards a single overarching goal: building a sustainable, competitive, and autonomous battery ecosystem in Europe. It is a multi-pronged approach, guided by targets set for the coming decades.

The first important regulatory tool is the Green Deal Industrial Plan.[3] With it, the EU seeks to become the "home of clean tech manufacturing".[4] Key aspects of the plan include creating a favourable regulatory and financial

1 energy.ec.europa.eu https://energy.ec.europa.eu/news/focus-supercharging-transition-energy-storage-solutions-2025-09-16_en

2 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

3 The Green Deal Industrial Plan - European Commission https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en

4 single-market-economy.ec.europa.eu https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

environment for clean technologies, addressing the EU's import dependency for key commodities and technologies, and supporting the transition of European industry toward climate neutrality. This is in conjunction with the Net-Zero Industry Act (NZIA), which sets an ambition that net-zero tech (including batteries) should meet "at least 40% of the EU's annual deployment needs by 2030".[5] These two tools aim to create market signals and investment certainty for battery manufacturers.

Another way the EU is pushing for a European battery ecosystem is through Strategic Alliances and Funding. Initiatives like the European Battery Alliance and Important Projects of Common European Interest (IPCEIs) have supported battery projects. EU grants (Innovation Fund, etc.) now total billions of euros (e.g. €3 billion announced in 2023 plus €852 m in 2025) to stimulate cell factories. These aim to attract investment and create jobs. [6]

At the core of the EU's industrial approach to battery competitiveness lies a three-part logic: securing the supply of critical inputs, ensuring sustainable production, and accelerating industrial deployment through favourable regulation and finance. To operationalise this vision, Brussels has introduced a suite of complementary instruments addressing each stage of the value chain. One of the key aspects of battery production is critical raw materials. These are minerals and metals that are essential for key technologies. At the EU level, this has been addressed through the Critical Raw Materials Act (CRM),[7] which recognises that battery gigafactories require vast minerals (Li, Ni, Co, etc...). The CRM Act mandates by 2030 that at least 10% of EU consumption of strategic minerals be sourced by EU mining, 40% processed

5 Net-Zero Industry Act - European Commission https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/net-zero-industry-act_en

6 energy.ec.europa.eu https://energy.ec.europa.eu/news/focus-supercharging-transition-energy-storage-solutions-2025-09-16_en

7 Critical Raw Materials Act - Internal Market, Industry, Entrepreneurship and SMEs https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en

and 25% recycled.[8] This is to reduce extreme import dependence (today 83% of Lithium-ion (Li-ion) capacity is in China).[9]

While securing access to raw materials is vital for scaling battery production, the EU also places strong emphasis on how batteries are made. This is where the Batteries Regulation comes in.[10] It aims to ensure that growth in the sector aligns with sustainability and ethical standards. It imposes standards on carbon footprint, recycled content and due diligence in battery supply chains. The Commission notes this "ensures ambition on batteries does not come at environmental cost".[11]

There is then the quite liberal approach of using the Net-Zero Europe Platform and Strategic Projects. This focuses on projects designated as "strategic" under NZIA and that therefore get fast-track permits.[12] This allows for a single point of contact for permits and a permissive state-aid framework support gigafactories. The EU's goal is clear: strategic autonomy and "green" jobs from a domestic battery industry.[13]

Complementing these efforts, the EU will also introduce a digital battery passport (DBP) by 2027, aiming to ensure transparency and traceability across the entire battery lifecycle, from raw materials to recycling. This passport has come with its own share of critics, as smaller companies may struggle with the technical and financial burden of complying with the DBP

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8 single-market-economy.ec.europa.eu https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en

9 energy.ec.europa.eu https://energy.ec.europa.eu/news/focus-supercharging-transition-energy-storage-solutions-2025-09-16_en

10 Regulation - 2023/1542 - EN - EUR-Lex https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng

11 energy.ec.europa.eu https://energy.ec.europa.eu/news/focus-supercharging-transition-energy-storage-solutions-2025-09-16_en

12 single-market-economy.ec.europa.eu https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act/strategic-projects-under-nzia_en

13 single-market-economy.ec.europa.euenergy.ec.europa.eu https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

requirements, especially given the 90+ mandatory data points. Additionally, there's a lack of common data standards across the battery supply chain, making it hard to ensure interoperability between different systems and platforms.

These instruments reflect the EU's preference for regulatory coordination over direct industrial direction. While they provide coherence with the EU's broader climate and strategic goals, they may also constrain agility and responsiveness, which are qualities that are increasingly vital in a fast-evolving battery industry shaped by global competition with China and the US as well as the rapid technological change that this entails.

2. Global Battery Industry Strategies

Discussions surrounding battery production and its supply chain cannot be done without analysing its strongest actor, China. China dominates global battery production (83% of Li-ion capacity in 2023). Its strategy has been state-driven industrial policy: subsidies, cheap credit and rapid scale-up. Chinese battery firms (CATL, BYD, etc.) benefit from integrated supply chains and home EV market protection. The IEA notes China processes 50% of global lithium and cobalt and accounts for 85% of global battery cell production capacity (battery cell capacity is the amount of electrical energy a battery cell can store and deliver). Its focus has been on cost leadership: battery pack prices in China are 10–20% lower than in Europe/US. Recent Chinese foreign direct investments into the EU (like CATL's €7.3 bn gigafactory in Debrecen) demonstrates the exportation of this model to Europe.[14]

On the opposing side, we have the US. The US Inflation Reduction Act (IRA, 2022) initially injected large tax credits for domestic battery and EV production, including $35/kWh for U.S.-made cells. This led to a surge in battery investments from $2 billion to $12 billion per quarter. The IRA tied credits to local content requirements, aiming to build a homegrown supply chain. However, under President Donald Trump's 2025 "One Big Beautiful

14 bruegel.org https://www.bruegel.org/policy-brief/smart-european-strategy-electric-vehicle-investment-china

Bill Act," most of these incentives have now been eliminated, including the $7,500 EV tax credit and production credits for battery manufacturers. This rollback has already led to project cancellations, investment slowdowns, and industry uncertainty. Automakers like Ford and Honda are delaying EV launches, and some are shifting back toward hybrids or internal combustion vehicles. While debate continues, the current US policy no longer actively incentivises battery plant construction at the federal level, which creates a sharp contrast with the EU's regulatory and strategic support.

While the EU, US and China vie for leadership, established Asian players like Japan and Korea remain critical to the global battery ecosystem. Their champions (Panasonic, LG, and SK) are key suppliers to the auto industry, often from factories on American soil. Meanwhile, emerging economies like India are entering the fray with ambitious industrial policies.

In this competitive landscape, "green tech sovereignty" has become a primary driver, overshadowing purely environmental goals. Both the US and EU are aggressively reshoring supply chains and building alliances to counter China's dominance, a concern sharpened by Beijing's control over rare earths. While the EU currently leads in real-world deployment with more EVs and renewables, it lags in low-cost production. This international context is no longer merely about competition; it is one of strategic rivalry, where every player is manoeuvring to secure its economic and industrial future.[15]

3. Current Status of Europe's Battery Industry

Despite commendable ambitions, Europe's share of battery production remains small. In 2023 the EU accounted for only 8% of global Li-ion capacity. The EU is still heavily import-dependent (about half of battery demand is met by imports).[16] Most EU cell capacity is operated by foreign-owned firms or joint ventures. In 2023 the combination of China+US+EU

15 bruegel.org https://www.bruegel.org/newsletter/how-do-europe-and-us-compare-clean-tech

16 energy.ec.europa.eu https://energy.ec.europa.eu/news/focus-supercharging-transition-energy-storage-solutions-2025-09-16_en

made 90% of batteries; China alone 83%. This high percentage represents significant infrastructure in the EU, as its market is large: electric cars are 20% of new sales, making Europe a top EV market. Yet battery assembly/gigafactory count is far below China's, and even Korea and Japan's. EU-based companies such as Northvolt, Verkor, ACC, etc… have raised Europe's profile, but some (such as Northvolt in 2024-2025[17]) have encountered financing setbacks or operational mismanagements.[18]

On a brighter note, Europe excels in research (Battery 2030+ initiative) and stringent standards, but its high labour/environment costs inflate production prices. The EU battery ecosystem (cells, packs, recycling) currently supports 90,000 jobs. Many of these are in component (anodes, cathodes, equipment) and recycling firms. The Batteries Regulation and R&D programmes aim to turn these into a competitive advantage, but today Europe mostly produces higher-end or specialised batteries rather than commodity cell mass-market.[19] The market has however clearly shifted in the direction of EV batteries, which now make up over 90% of energy-sector battery demand. EU battery prices here remain 10–20% higher than in China.[20]

4. Competitiveness and Strategic Challenges

When looking at their industries from a holistic view, EU manufacturing costs remain well above China's. The IEA notes that in 2023 battery prices were 10–20% higher in Europe (and US) than in China. Factors include higher labour and compliance costs, and lower production scale. By contrast, Chinese plants benefit from state aid and integrated domestic supply of materials. This cost gap forces European factories to rely on

17 'There was so much promise': How Northvolt tumbled into bankruptcy https://www.ft.com/content/09938004-21b9-4750-8fa2-9ed15c566d4e

18 bruegel.org https://www.bruegel.org/policy-brief/smart-european-strategy-electric-vehicle-investment-china

19 energy.ec.europa.eu https://energy.ec.europa.eu/news/focus-supercharging-transition-energy-storage-solutions-2025-09-16_en

20 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

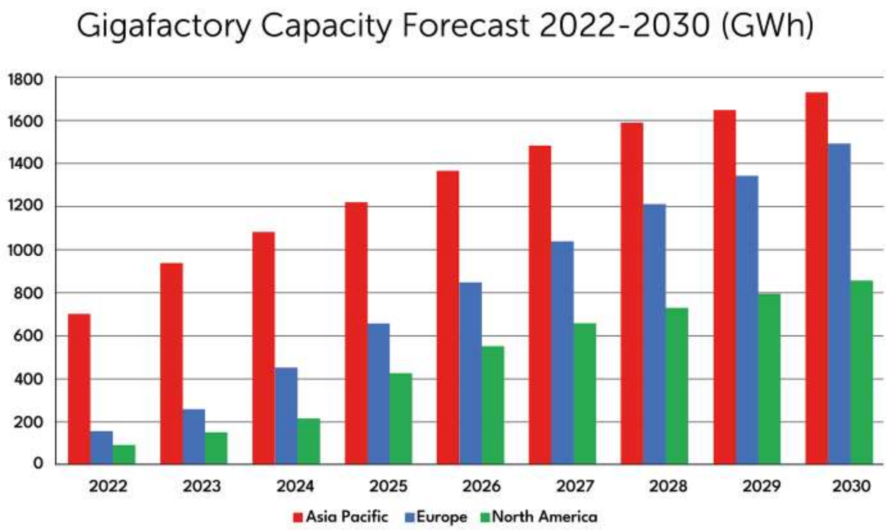
subsidies or focus on niche markets (such as high-performance or speciality chemistries). The persistent cost gap risks undermining Europe's ability to scale competitively, pushing manufacturers toward niche innovation rather than mass-market leadership. This is not helped by the EU's supply chain vulnerabilities: Europe has negligible amounts of mining of key minerals. Today China processes most battery minerals. If Europe simply builds plants without securing minerals, it risks building dependency on imports of ore or precursor chemicals. The CRM Act attempts to address this, but scaling geology takes time[21] that demand for battery minerals will rise 3–6 times by 2030, so delays in supply expansion could bottleneck manufacturing plans.[22]

The solution currently prefered by the EU is Gigafactories. These are large-scale battery manufacturing plants designed to produce cells and packs at high volume and lower cost, which is essential for powering electric vehicles (EVs), energy storage systems, and the clean energy transition. However, critics argue EU should not bet solely on gigafactories, as it is heavily centred on these already. Through initiatives like EBA and IPCEIs. For example, "right-sizing" EV batteries (avoiding oversized packs) and smart charging could cut material needs by 25%. Investing in second-life uses and recycling could also stretch resources. A heavy industrial focus risks neglecting other decarbonisation levers (grid upgrades, hydrogen for heavy vehicles, public transport). Moreover, if battery technologies shift to sodium-ion pr solid-state), for example, Europe's new plants might face obsolescence. The IEA notes emerging chemistries may challenge Li-ion's dominance and Europe's strategy must therefore consider these uncertainties. A decentralised model with smaller, more adaptive producers might offer an alternative, especially in areas where flexibility, specialisation, or local integration are valuable.

21 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en#:~:text=Setting%20benchmarks%20by%202030%20for,domestic%20capacities

22 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

Figure 1: Forecast of Gigafactory capacity by continent[23]



As can be seen in figure 1, the EU is at least aiming to catch up with China after 2030, however, building capacity for its own demand could still leave EU producers exposed. Global competition could flood markets with low-cost products (or impose tariffs). For instance, EU battery imports face almost zero duties, whereas US tariffs on Chinese batteries can be as high as 58%.[24] Without similar protections, EU factories may struggle to compete on price. The NZIA's 40% (or 90%) target is politically ambitious, but achieving it will be very challenging. Many EU-supported ventures have been delayed or scaled back. Northvolt's recent bankruptcy serves as a cautionary tale. Leaning heavily on foreign investment (Chinese or Korean) can fill gaps, but raises questions of autonomy. EU policies risk overpromising on "tech

23 Lithium-ion battery gigafactory database | Feature | Automotive Logistics https://www.automotivelogistics.media/ev-and-battery/lithium-ion-battery-gigafactory-database/211890

24 spglobal.com https://www.spglobal.com/automotive-insights/en/blogs/2025/08/why-europe-is-losing-the-gigafactory-race-to-china

leadership" when Europe may instead become a site for assembly under foreign technology licenses.[25] While partnerships and joint ventures can accelerate learning, true technology transfer remains limited, especially from Chinese firms, which often avoid sharing proprietary knowledge. This constrains Europe's ability to build deep, homegrown expertise.

According to research by the China Strategic Risks Institute, there are currently no examples where Chinese green investment in EU Member States has led to technology transfer. In the case of Shanghai Putailai's planned battery plant in Sweden, the Chinese company cancelled its investment rather than transfer technology to local partners.[26]

Sam Goodman, Senior Policy Director of the China Strategic Risks Institute, notes that China is not the only player when it comes to EV battery technology. Japanese and South Korean companies have long operated in this sector and Goodman argues that due to them rapidly losing market share to Chinese competitors they may be more open to joint-ventures with EU partners and actual transfers of technical knowledge.

Addressing China's growing role in European battery production, EU Trade Commissioner Maroš Šefčovič argued that: "The EU is not interested in trade wars," adding that the bloc was looking to rebalance its relationship with China and tackle all areas "where we simply feel that our relationship is not fair."[27] On the other hand, some political and industrial voices from Viktor Orbán, who frames Sino-Hungarian cooperation as essential to "bringing development capacities" to Europe, to analysts who highlight the potential for know-how spillovers, have suggested that such transfer is bound to

25 bruegel.org https://www.bruegel.org/policy-brief/smart-european-strategy-electric-vehicle-investment-china

26 China's Electric Vehicle Challenge to Europe: Red Flags and Red Lines — China Strategic Risks Institute https://www.csri.global/research/chinas-ev-challenge-to-europe

27 5 takeaways from Maroš Šefčovič's trade czar confirmation hearing – POLITICO https://www.politico.eu/article/maros-sefcovics-trade-czar-european-commission-meps-success-business-us-eu/

occur, the empirical record tells a different story.[28]

Ultimately, the strategic challenge for Europe is not just about capacity building and large scale investment, but to ensure that this build-out translates into genuine technological autonomy and a resilient, cost-competitive industry, rather than a new form of assembly-line dependency. It is important to note that the EU should invest in smaller, more agile manufacturing hubs. This would be done with factories that are adaptable, resource-efficient, and capable of producing smart, sustainable batteries aligned with emerging technologies. This approach is especially relevant given the current demand-side crunch in the EV market, where slower-than-expected uptake risks leaving large-scale production underutilised. Smaller, modular facilities offer the flexibility to scale with demand, experiment with next-generation chemistries, and respond to shifting market and technological trends.

5. Industry Sustainability and Supply-Chain Considerations

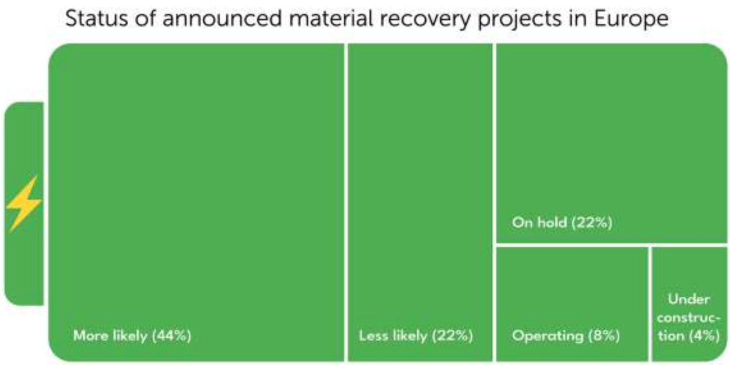
Even though battery investment is a necessity to move forward in the green transition, it is important to remember that large battery plants have significant energy and material footprints. Europe's stringent rules (Batteries Regulation) aim to mitigate this, but real-world impacts depend on implementation. There is debate whether the carbon cost of European production (often powered by decarbonised grids) is lower than shipping from Asia, however, the Batteries Regulation's carbon footprint requirements will partly address this by mandating transparent lifecycle emissions reporting, helping ensure that battery production aligns with EU climate goals and discourages carbon-intensive imports.

Another major way to mitigate environmental impacts is by pushing the EU

28 Chinese EV giant BYD selects Budapest for European headquarters and R&D center - Electric & Hybrid Vehicle Technology International https://www.electrichybridvehicletechnology.com/news/chinese-ev-giant-byd-selects-budapest-for-european-headquarters-and-rd-center.html

in the direction of a circular economy. Recycling is a key part of Europe's strategy and recovered Li, Co, Ni can supplement mining. The IEA draws attention to recycling as a way to make supply chains "more sustainable and less geographically concentrated". The CRM Act's 25% recycling target (by 2030) and EU mandates on recycled content (through the Batteries Regulation) encourage this. However, recycling technologies and economies of scale are still nascent. Scaling recycling will take concerted policy (such as recycling credits) and investment.[29] It is important to note that recycling lithium in Europe could cut CO_2 emissions by nearly 20% compared to importing refined lithium from Australia and China. Yet, Europe is not positioned to seize this sustainability and resilience opportunity. Current recycling capacity is ten times below what's needed by 2030. As can be seen in figure 2, although over 30 material recovery projects (extracting valuable raw materials from used batteries or industrial waste so they can be reused) are planned or underway, nearly half face delays or uncertainty due to high energy costs, limited technical expertise, and insufficient financial support[30].

Figure 2: **Status of announced material recovery projects in Europe**[31]



29 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

30 Battery recycling report https://www.transportenvironment.org/uploads/files/2024_12_Battery_recycling_report.pdf

31 Battery recycling report https://www.transportenvironment.org/uploads/files/2024_12_Battery_recycling_report.pdf

Another important aspect is the social one. Large-scale battery mining (even if in EU) can be socially sensitive, with aspects such as water use or local opposition can come into play. The CRM Act mentions ESG standards and "mutually beneficial partnerships" to avoid exploitation. On geopolitical side, EU decision-makers worry that heavy reliance on Chinese (or Russian) resources leaves them vulnerable. Building some domestic refining (10% goal) is a hedge, but still limited.

Most importantly, the IEA notes that stalled battery deployment would slow renewables growth and prolong fossil fuel imports (hurting EU energy security). Thus, from an energy-security lens, more batteries and associated manufacturing, are desirable. But it must be accompanied by resilient supply chains.[32] The NZIA and CRM Act together try to create a more integrated value chain within Europe, yet true resilience may require global coordination (international resource partnerships) and risk mitigation (stockpiling and strategic partnerships).[33]

6. Case Study: Hungary

Hungary, among Central/Eastern EU states, has become a hotspot for battery and EV investment. Notably, China's CATL is building a 7.3 billion euro gigafactory, targeting a capacity of 100 GWh per year by 2030. It started construction in 2022 near Debrecen.[34] South Korea's BYD is also investing in Hungary (electric buses and a €4 bn battery/Electric Vehicle project). These exemplify how EU policies (low taxes, incentives, strategic location) can draw foreign gigafactories into Europe.

The Hungarian case shows potential economic gains: tens of thousands

32 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

33 single-market-economy.ec.europa.eu https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en

34 China's CATL to build $7.6 bln Hungary battery plant to supply Mercedes, BMW | Reuters https://www.reuters.com/business/autos-transportation/chinas-catl-build-new-756-bln-battery-plant-hungary-2022-08-12/

of jobs, technology transfer, and industrial renewal in formerly Internal Combustion Engine manufacturing regions. However, it also illustrates dependency. The plants rely initially on imported equipment and materials (as Bruegel notes, much high-value machinery is shipped from China during construction).[35] Long-term local economic participation may be limited unless policy ensures local supplier development and training (early evidence suggests gradual localisation of some supply chains).

Hungary's experience suggests that attracting investment can bridge capacity gaps but does not automatically build EU-wide expertise. EU (and Hungarian) strategy will need safeguards to maximise spillovers: e.g. vocational training, R&D partnerships, and conditions for domestic sourcing. This microcosm echoes the broader question: can Europe turn foreign-led plants into genuine "European" battery industry, or will it remain assembly territory? According to the IEA, this is a global trend: "many vehicle manufacturers entering joint ventures with battery producers and mining firms".[36] Hungary is currently moving in a direction which illustrates this dynamic.

7. Conclusion

Europe's ambitious strategy to build a domestic battery industry is a direct and necessary response to the imperatives of climate action, energy security, and geopolitical rivalries. The analysis presented in this chapter, however, suggests that while the ambition is justified, the idea that future competitiveness is guaranteed might be exaggerated. The EU has constructed a sophisticated regulatory framework, from the Net-Zero Industry Act to the Critical Raw Materials Act, to nurture this strategic sector. Yet, the stark reality remains: Europe's manufacturing costs are significantly higher than China's, its supply chains for critical minerals are vulnerable, and its current global production share remains modest.

35 bruegel.org https://www.bruegel.org/policy-brief/smart-european-strategy-electric-vehicle-investment-china
36 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

To succeed, the EU must avoid a narrow "gigafactory fetishism" and embrace a more holistic industrial strategy. This includes doubling down on its strengths in recycling and circular economy principles, promoting the "right-sizing" of batteries to conserve materials, and fostering innovation in next-generation chemistries like sodium-ion and solid-state. A diversified approach that also invests in smart grids and alternative clean transport solutions will allow for an energy transition that is not held hostage by a single technological pathway.

From a liberal economic perspective, the EU's subsidy-driven approach presents a strategic dilemma. In an ideal world, innovation thrives in open, competitive markets. The current reality, however, is one of significant global market distortion, primarily driven by state-led strategies in China and the now-uncertain landscape in the US. In this context, temporary and targeted subsidies are a necessary defensive tool to prevent the complete erosion of Europe's industrial base and to level the playing field. The critical challenge for policymakers is to design these interventions to be transitional, avoiding the creation of permanent subsidy dependencies. The focus must be on creating the underlying conditions for long-term competitiveness: robust R&D, a skilled workforce, and a single market that fosters scale and efficiency, so that the industry can eventually thrive without perpetual state aid.

As the IEA rightly warns, "Failing to scale up battery storage in line with renewables would risk stalling clean energy transitions."[37] Batteries are an indispensable component of a decarbonised Europe. The central question is not whether to support the industry, but how to do so intelligently. Europe's success will depend on its ability to marry strategic intervention with market-driven innovation, ensuring that its battery ecosystem becomes not just a protected venture, but a genuinely competitive and resilient pillar of its future economic and environmental security.

Europe's battery strategy should scale up, but it must also evolve. Ányos Jedlik, the Hungarian priest–physicist who built one of the first model electric vehicles in the 19th century, embodied the spirit of compact,

37 Batteries and Secure Energy Transitions – Analysis - IEA https://www.iea.org/reports/batteries-and-secure-energy-transitions

ingenious innovation. That same spirit should guide Europe today. Rather than relying solely on massive gigafactories, the EU should also invest in smaller, more agile manufacturing hubs; factories that are adaptable, resource-efficient, and capable of producing smart, sustainable batteries aligned with emerging technologies. This diversified, innovation-led approach will better position Europe to catch up and also lead in the global battery race.

Chapter 8

Policy Brief: Climate Impacts of Battery Production in Europe Aligning battery production with EU climate objectives

Diána Ürge-Vorsatz and Réka Boróka Ürge
Vice Chair, IPCC

1. Introduction and Background:

This policy brief examines the climate impacts of battery production in Europe, with a focus on aligning industrial practices with EU climate objectives and global sustainability goals. As demand for battery electric vehicles (BEVs) rises due to regulation and the European Green Deal, the environmental footprint of battery manufacturing becomes increasingly critical. The paper explores both the mitigation potential and ethical considerations of the sector, emphasizing the need for responsible production and systemic reform.

Bringing battery supply chains to Europe could boost strategic autonomy, avoid the export of European consumption related environmental impacts, and support climate justice - provided that proper environmental safeguards, inclusive planning and transparency are secured.

The structure of the paper is as follows: it begins with an overview of BEV climate benefits and ethical concerns, followed by a detailed outlook on battery production drivers, emissions sources, and reduction strategies. A strategic SWOT analysis highlights strengths, weaknesses, opportunities, and threats. The final sections offer policy and expert recommendations to guide sustainable development and conclude with key takeaways for decision-makers.

The European Union is the second largest market for electric vehicles (EV) in the world (IEA, 2024) with demand rising due to Regulation (EU) 2023/851[1], which

- Mandates a 55% reduction in greenhouse gas emissions from new cars by 2030 (relative to 2021 levels).
- Requires a 50% reduction of greenhouse gas emissions from new vans by 2030.
- Requires a 100% reduction in greenhouse gas emissions from new cars and vans after 2035.

However, fragmented national policies and reliance on imported raw

1 https://eur-lex.europa.eu/eli/reg/2023/851/oj/eng https://eur-lex.europa.eu/eli/reg/2023/851/oj/eng

materials diminish some of the advantages otherwise provided by the European single market. According to the executive director of the European Lithium Institute, the EU is currently importing 81% of extracted lithium and 100% of processed lithium, which complicates low-carbon transitions[2].

Batteries account for 10-30% of the entire life cycle emissions of a battery-powered electric vehicle BEV (IEA, 2020[3]). Although battery production emissions may not majorly impact BEV life cycle emissions, they could hinder the EU's greenhouse gas reduction goals if left unaddressed.

Estimates for BEV battery emissions vary: PNA Nexus[4] projects up to 8.1 gigatonnes of CO2 equivalent by 2050 with rapid EV adoption and nickel-based chemistries, while the World Economic Forum estimates the battery value chain could emit 182 Mt CO2 in 2030. Therefore, addressing the greenhouse gas footprint of the batteries is both an obligation and a valuable opportunity to maximise the mitigation potential of BEVs. Enhancing the sustainability of this phase can strengthen the case for broader adoption of battery technologies and make the transition to electrification even more persuasive. The EU battery regulation, Regulation 2023/1542 is a good premise for this, but it does not capture all the mitigation potential of the battery production phase. The regulation will gradually introduce reporting requirements and carbon footprint limits for batteries used in electric vehicles, light means of transport (e.g., e-bikes and scooters), and rechargeable industrial batteries, starting in 2025[5]. The overall climate impact of the BEV battery production will also heavily depend on whether the emissions from the batteries can be offset from the lower end use emissions of the vehicle. Thus, climate impacts of BEV battery production cannot be separated from the vehicle itself.

2 https://www.euronews.com/green/2024/05/09/critical-raw-materials-lithium

3 https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf

4 https://academic.oup.com/pnasnexus/article/2/11/pgad361/7451193

5 https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng

Battery Electric Vehicles and Climate Benefits

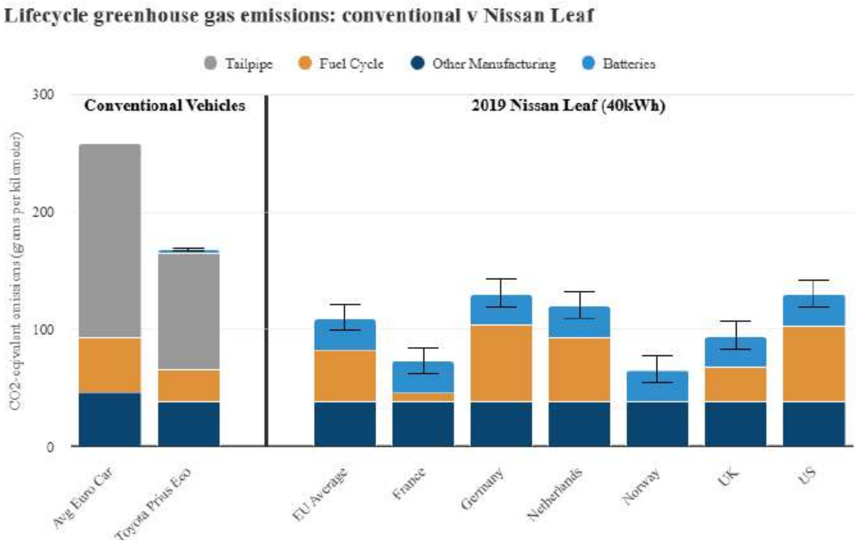
The surge of the popularity of Battery Electric Vehicles(BEVs) has sparked debates around their benefits for the climate, with multiple sources and people on social media claiming that BEVs would actually increase emissions compared[6] to Internal Combustion Engines. For instance, daily mail[7] writing that "driving an electric car simply displaces carbon emissions from roads to distant power stations"[8]. These misleading claims usually stem from using out of context data, as the payback timeline of BEVs can be quite high if the electricity used as fuel comes from high carbon sources. However, as the IPCC states, battery electric vehicles (BEVs) have lower lifecycle greenhouse gas emissions than internal combustion engine vehicles when BEVs are charged with low-carbon electricity. According to Carbon Brief, even when calculating battery models with high production emissions (Asia), an EV has lower lifecycle greenhouse gas emissions than an average European car. 1. Figure illustrates the projected lifecycle emissions of a Tesla Model 3 assuming its battery is manufactured in Asia, where coal remains a dominant source of electricity, similar to the production conditions for Nissan Leaf batteries. The analysis is based on the long-range 75 kWh version of the vehicle.

6 https://x.com/mattwridley/status/1677574778247421953

7 https://www.dailymail.co.uk/sciencetech/article-12317297/Why-electric-car-near-green-think-hidden-eco-pitfalls-NetZero-causes-pin-up.html

8 https://www.dailymail.co.uk/sciencetech/article-12317297/Why-electric-car-near-green-think-hidden-eco-pitfalls-NetZero-causes-pin-up.html

Figure 1: Comparison of lifecycle greenhouse gas emissions of conventional cars and BEVs



Source: Carbon Brief https://www.carbonbrief.org/factcheck-how-electric-vehicles-help-to-tackle-climate-change/

The avoided emissions from BEVs compared to Internal Combustion Engines are estimated to reach 2 Gt of CO2 equivalent (CO2-eq) in 2035(IEA, 2024). In the European Union we can already see the mitigation effects of electric vehicles. Between 2019 and 2022, average CO_2 emissions from newly registered passenger cars in Europe declined by 27%, while emissions from new vans saw a 10% reduction. This downward trend is primarily attributed to the rapid increase in the adoption of zero-emission vehicles across the region. Reports warn that growing consumer demand for larger and heavier EV models could undermine these environmental benefits, diminishing the overall gains from electrification (Pardi, 2021)[9].

9 https://www.researchgate.net/publication/353135366_Prospects_and_contradictions_of_the_electrification_of_the_European_automotive_industry_the_role_of_European_Union_policy

Battery ELectric Vehicles and Ethical Concerns

Battery electric vehicle (BEV) technologies entail inherent trade-offs and raise a range of environmental concerns, as discussed in a previous chapter. However, if European consumers wish to continue accessing luxury goods, there is an ethical responsibility to address, the environmental impacts associated with their production, since merely displacing environmentally harmful production to lower-income countries poses significant moral issues.

It is also important to recognize the tension between individual and collective responsibility: the adoption of electric vehicles by private consumers will not suffice to decarbonize mobility and transport systems. For example, replacing all private vehicles, whose utilization rates are estimated at approximately 4%, and in some cases below 1%[10], would not achieve sufficient reductions in transport-sector emissions. The transition to electric mobility must therefore be accompanied by measures that reduce dependence on private vehicle use, including the development of 15-minute walkable cities, expansion of shared mobility schemes, improved public transport, and enhanced cycling infrastructure.

2. Outlook: Future Prospects and Challenges for Battery Electric Vehicles

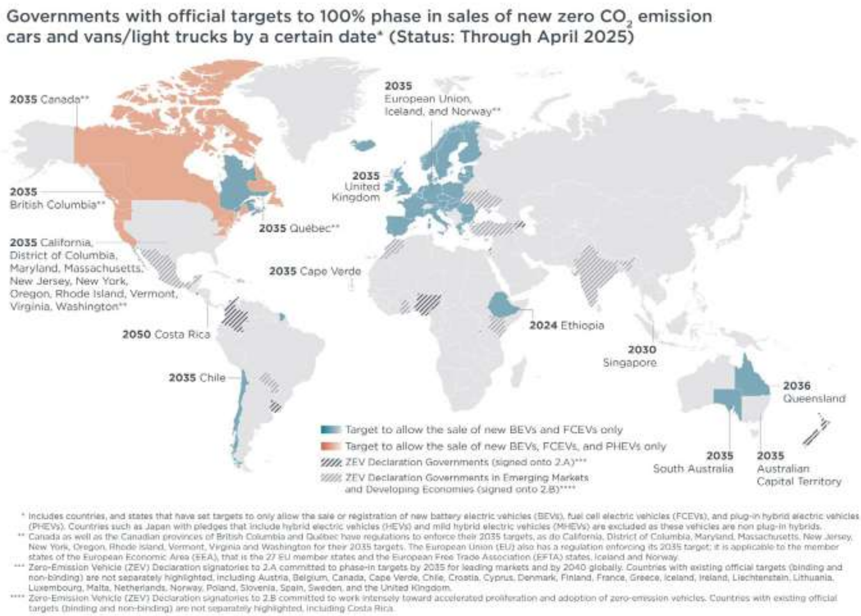
Key Drivers

The global transition towards BEVs and therefore BEV battery production is driven by the increased demand which has been encouraged by global treaties such as The Paris Agreement adopted in 2015 under the United Nations Framework Convention on Climate Change(UNFCCC), and the Zero Emission Vehicle Declaration, which was signed by more than 44 countries at COP26. Globally multiple sub-national and national governments have set targets to end the sale or registration of internal combustion engines

https://energytransition.org/2017/10/private-car-ownership-is-ridiculously-wasteful/#:~:text=Admittedly%2C%20comparing%20cars%20and%20power,It's%20ludicrous

(2. Figure)[11], including the European Union, with the previously mentioned target of a 100% reduction of greenhouse gas emissions from private automobiles by 2035.

Figure 2



Source: https://zevtc.org/tracking-progress/phaseout-light-duty/

Components of BEV Batteries and their Related GHG Emissions

The main sources of life-cycle greenhouse gas emissions from a BEV battery are(IEA,2020):

- Materials: Emissions from mining and refining, particularly aluminium, as well as producing active materials like nickel, cobalt, and graphite.
- Battery production: Energy-intensive cell assembly, carried out in "dry rooms" with extremely low humidity (<1%) and strict environmental controls to prevent contamination and ensure safety.

11 https://zevtc.org/tracking-progress/phaseout-light-duty/

The components of a Li-ion battery (LIB), most commonly used in BEVs, are:

- cathode, the components of which include lithium, nickel, cobalt, manganese
- a graphite anode
- and a lithium-salt electrolyte,
- aluminum and copper in the pack.

The main cathode types in BEVs are lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), and lithium iron phosphate (LFP), with NMC being the most common today.

Raw materials are processed into the main battery parts, cathode, anode, separator, and electrolyte, that form the cells. These cells are then combined with systems like the BMS and thermal controls inside a casing to create the battery pack. Beyond material production and refining, a major source of greenhouse gas emissions in manufacturing is the high energy demand of cell assembly, which requires ultra-dry, tightly controlled environments. (IEA, 2020)

While the analysed scientific literature states that battery production is energy intensive, different reviews estimate varied ranges for the greenhouse gas emissions. The International Council on Clean Transportation(ICCT) approximates the number to be from 56 to 494 kg CO2/kWh[12], the Swedish Energy Agency[13] 61-106kg CO2-eq/kWh and the latest review in PNAS Nexus from 2023 resulted in an estimate of 39–196-kgCO2eq/kWh[14]. The variability of the numbers is likely due to differences in battery specifications and technologies, geographical locations, and life cycle inventory data; and material, energy, local energy mix and processes emission factors.

The main contributors to greenhouse gas emissions in the raw materials stage are aluminium (used in both the vehicle body and battery parts) and key Li-ion battery materials such as cobalt, nickel, and natural or

12 https://theicct.org/wp-content/uploads/2021/06/EV-life-cycle-greenhouse gas_ICCT-Briefing_09022018_vF.pdf

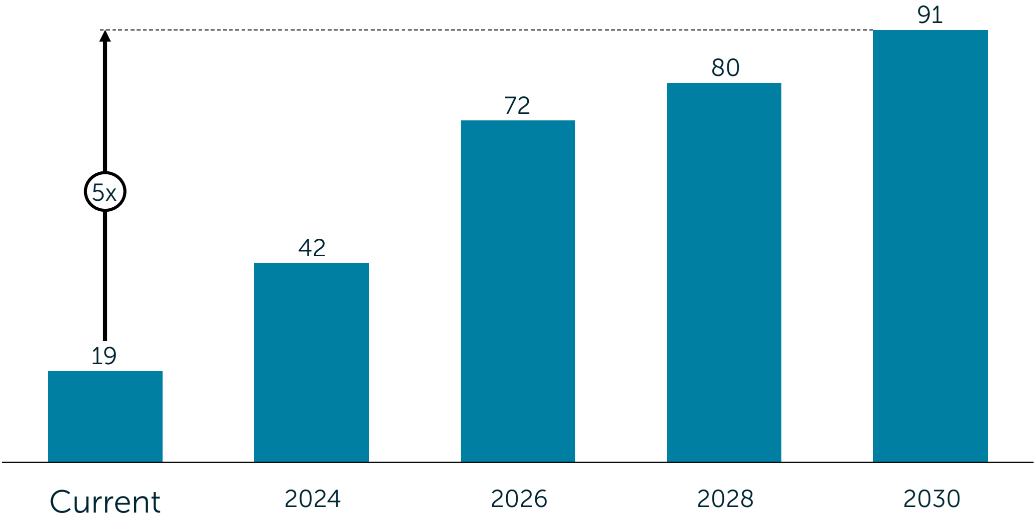
13 https://ivl.diva-portal.org/smash/get/diva2:1549551/FULLTEXT01.pdf

14 https://academic.oup.com/pnasnexus/article/2/11/pgad361/7451193

synthetic graphite. These materials rely on complex global supply chains, and their mining, processing, and refining to battery-grade quality require large amounts of energy. Emissions can be lowered mainly by sourcing low-carbon energy for production and refining, or by increasing the use of recycled materials.

Reported CO2 emissions from battery production in the EU were 19 Mt in 2023(WWF, 2024). According to projections EU battery production is expected to drive a nearly fivefold increase in greenhouse gas emissions, reaching more than 90 Mt CO_2-eq annually by 2030, primarily due to the dominance of nickel manganese cobalt oxide(NMC) and lithium iron phosphate(LFP) chemistries Figure 3)

Figure 3: Projected CO2 emissions from Lithium-ion battery production in the EU



Source: WWF https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Wald/wwf-study-green-responsible-batterie-production-eu.pdf

Emissions REduction Potential from RAw Materials in the European Union

For the EU, access to raw materials poses a major challenge, with demand for lithium projected to be 18 times higher and for cobalt five times higher by 2030 compared to the bloc's current production levels (European Commission, 2023)[15]. Depending on the origin of raw materials, greenhouse gas emissions from lithium and nickel refinery in the EU can vary by a factor of five (WWF, 2024). For Lithium, spodumene from Canada and Australia have the highest climate mitigation potential, as the industry has access to a relatively clean electric grid. Refining nickel has the lowest possible emissions if it is obtained from additional sulphide sources or from Canada, rather than from laterite ore processed in other locations (WWF,2024).

The rising demand for battery raw materials is also fuelling interest in deep seabed mining, made more feasible by recent technological advances (WEF,2019). While this could provide new economic opportunities and raw material sources by 2030, the environmental risks to ocean ecosystems remain poorly understood and potentially irreversible, including significant impacts on carbon sequestration (WEF, 2019). Given the limited knowledge of the deep ocean, careful evaluation of economic viability and thorough research into environmental consequences are essential before large-scale exploitation begins.

Higher throughput manufacturing lowers the greenhouse gas intensity of cell assembly by improving energy efficiency per kWh produced. Rising battery demand and large-scale production have already helped cut life-cycle emissions. (Kelly et al, 2019)

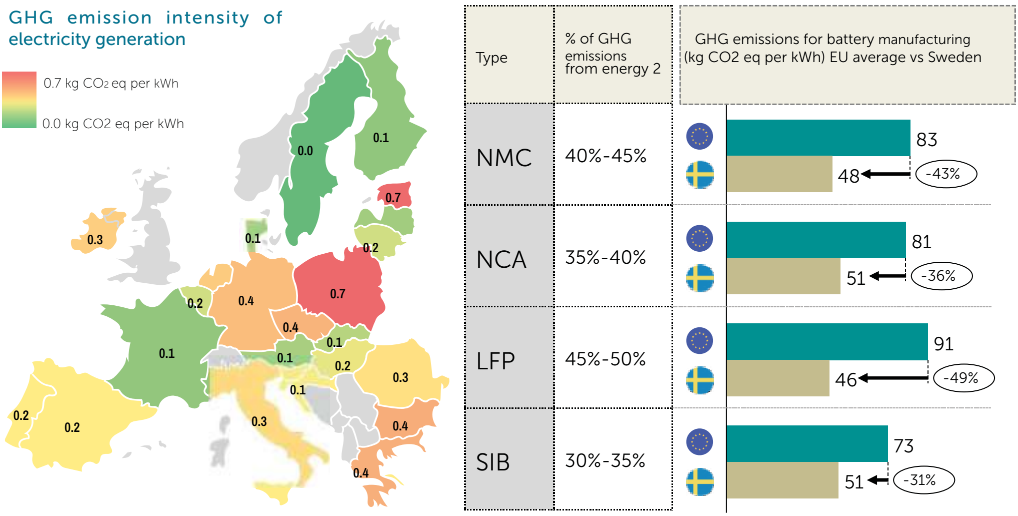
The carbon footprint can be reduced further by using low-carbon energy. For a Chinese battery case, over 80% of assembly emissions came from natural gas for heating (mainly dry rooms and electrode drying). Switching all energy inputs to renewable electricity could lower the battery's greenhouse gas footprint by about 29% (Kelly et al, 2019).

On an EU level for every battery chemistry, cell manufacturing energy (electricity and heat) causes the largest share of greenhouse gas emissions. The comparison of greenhouse gas emissions from battery production

15 https://ec.europa.eu/economy_finance/arc2023/documents/papers/Gyorffy%20D.%20-%20Diverging%20Paths%20to%20Zero-Emissions%20Mobility%20The%20political%20economy%20of%20building%20an%20EV%20battery%20industry%20in%20Hungary%20and%20Sweden%20.pdf

across EU countries, as a result of their respective energy mix, shows that by using renewable energy in battery production, emissions can be reduced by 30% to 50% (Figure 4).

Figure 4: Share of greenhouse gas emissions from manufacturing energy (electricity and heat) in battery cell production (%) and impacts from emissivity of energy input (kg CO2 eq per kWh) (SIB: Sodium-ion Batteries)



Source: WWF, 2024 https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Wald/wwf-study-green-responsible-batterie-production-eu.pdf

A potential way to cut greenhouse gas emissions from the heat used in battery production is using renewable heat sources like biomethane, provided they are available at a competitive cost(IEA,2020) The potential impact of this has not yet been quantified.

Recycling Batteries to Reduce Greenhouse Fas Emissions and Alignment with Circular Economy Strategies

Existing recycling technologies are both energy- and greenhouse gas intensive and remain unprofitable[16] and in the EU currently recovering lithium through recycling is a major challenge, because it is not economically competitive with primary sources (Halleux,2022[17]). A recent study published in Nature Communications found that the battery recycling process examined produced 58% to 81% fewer greenhouse gas emissions compared to the mining and processing of new materials (Machala, M.L., Chen, X., Bunke, S.P. et al, 2025)[18]. It is important to note that since battery recycling is energy intensive, the energy mix of the grid used for recycling has a huge impact on the greenhouse gas emissions of the process.

Emissions Reduction through Cross Sector Measures

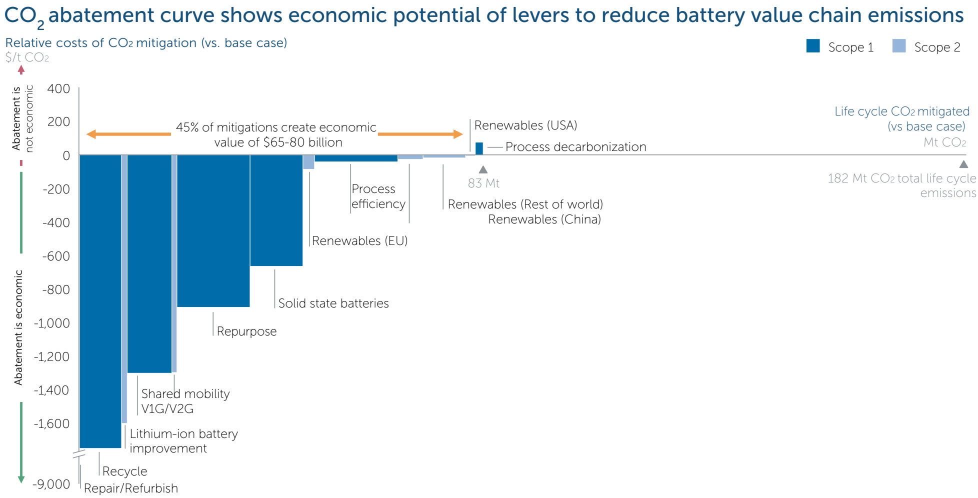
There is an opportunity to halve the greenhouse gas emissions of the battery value chain while doubling the economic impact of batteries (WEF,2019) with a combination of demand side and economic measures. Figure 5 presents the effects and costs of various improvement levers as a carbon abatement cost curve, with the most cost-effective measures displayed on the left. Some levers show negative costs, indicating that they can reduce production expenses. For instance, V1G and V2G enable a reduction of 17 Mt of emissions while also creating potential revenue streams, as vehicles connected to the power grid can offer storage capacity at low cost. When combined, the analysed levers could cut greenhouse gas emissions from 182 Mt to approximately 100 Mt (Scopes 1 and 2) while generating net cost savings.

16 https://ec.europa.eu/economy_finance/arc2023/documents/papers/Gyorffy%20D.%20-%20Diverging%20Paths%20to%20Zero-Emissions%20Mobility%20The%20political%20economy%20of%20building%20an%20EV%20battery%20industry%20in%20Hungary%20and%20Sweden%20.pdf

17 https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)689337

18 https://www.nature.com/articles/s41467-025-56063-x

Figure 5: Circular economy and innovation lever impact on life cycle greenhouse gas intensity of battery production in 2030



Source: WWF, 2019 https://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf

Innovations

One of the notable recent innovations in the field of battery technology has been the development of sodium-ion batteries. While current studies suggest that their overall carbon footprint is not yet significantly lower than existing alternatives, further research is needed to assess their potential, particularly given sodium's greater availability within the European Union.

3. Strategic Analysis (SWOT):

This SWOT analysis evaluates the EU battery and BEV sector's role in the green transition, weighing its innovation and climate alignment against environmental risks and public resistance. It aims to guide policy and industry toward sustainable, socially accepted solutions.

Strengths:

- Research & Development leadership in alternative battery and green technology. For example, Volkswagen played a key role in launching the first ever sodium ion battery powered BEV[19]

- Alignment with EU climate goals under the European Green Deal and Fit for 55, EU regulation 2023/851, and global goals like the Paris Agreement
- Environmental responsibility and climate justice. Battery production does have environmentally polluting aspects, (discussed in another chapter). However, if people living in the EU want to keep using private vehicles, we must take responsibility and bear the polluting impacts of the production.

Weaknesses:

- According to the European Environmental Agency, if BEVs are fuelled by coal, the manufacturing stage emissions cannot be offset by per kilometre use stage emissions
- Opportunities:
- Creation of green jobs. Total jobs in the sector could be more than 300,000 by 2030, if the EU maintains its current targets for electric vehicles(EEA)[20]
- Contribution to green transition, just transition and global emission reduction
- Ensure that batteries used in the EU align with EU standards, have control over the production parameters

Threats:

- Public backlash and dissatisfaction due to the environmental concerns, protests in Hungary[21] and Portugal[22]
- Increased energy demand from the high energy intensity production in the EU
- Cutting down of carbon storing forests for factories and mining

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19 https://sodiumbatteryhub.com/2023/12/28/volkswagen-backed-ev-sodium-ion-battery-car/

20 https://transportandenergy.com/2025/06/11/european-battery-supply-chain-could-create-250k-jobs/

21 https://www.euronews.com/green/2024/09/08/hungarian-families-say-area-risks-becoming-a-battery-wasteland-in-wake-of-chinese-lithium-

22 https://www.reuters.com/world/europe/portuguese-anti-mining-groups-urge-suspension-lithium-projects-after-pms-2023-11-08/

- Emerging methods for the extraction of raw materials could disturb ecosystems and lead to greenhouse gas emissions e.g deep seabed mining could disturb carbon sequestering sea ecosystems

4. Expert Recommendation:

Europe should strategically strengthen its domestic EV battery industry by relocating key segments of the supply chain to regions with low-carbon energy mix, enforcing rigorous lifecycle emissions reporting, and accelerating innovation in low-carbon technologies and circular practices. Shifting segments of the battery supply chain to Europe would strengthen strategic autonomy while offering a unique chance to gain control over production practices to ensure they comply with the EU's stringent environmental and climate standards and avoid outsourcing pollution to lower-income countries to align with climate justice principles.

Another crucial step is decarbonizing grid electricity across the EU. As highlighted several times, electricity use plays a role in the emissions of battery production, battery recycling, and whether the emissions from battery production can be offset through the life cycle of the BEV.

Additionally, pairing battery industry growth with demand side mitigation measure and urban planning reforms like walkable cities, shared mobility, and public transport ensures the maximization of mitigation potential in the transport sector and alignment with the Paris Agreement and Sustainable Development Goals (SDGs).

Some Specific Policy Recommendations Include:

- Place gigafactories strategically: Europe should prioritize locating gigafactories in regions with low-carbon electricity such as Sweden and France to reduce lifecycle emissions. Policies should also prevent deforestation for battery infrastructure, promote brownfield investments and require high throughput facilities.
- Enforce rigorous lifecycle emissions reporting: EU institutions must establish full supply chain transparency, from mining impacts to manufacturer carbon footprints to site-specific emissions including

energy mix and heat source. While the EU Battery Regulation enforces and requires carbon footprint reporting, the data has not been sufficiently disclosed publicly. For better policies and enforcement it would be beneficial to have easily accessible, public inventory of data from battery production sites. Standardized lifecycle greenhouse gas reporting also has to be enforced across the EU battery supply chain.

- Decarbonize the electricity grid: The source of the electricity used affects emissions from battery production, recycling, and whether production emissions can be offset through the battery electric vehicle lifecycle. Mandate renewable energy sourcing for battery manufacturing through Power Purchase Agreements (PPAs) or on-site generation. Using renewable energy in battery production, emissions can be reduced by 30% to 50%.
- Reduce pollution outsourcing: Bringing battery supply chains to Europe and requiring them to comply with EU's stringent environmental standards would prevent pollution export, and support climate justice.
- Accelerate innovation in low-carbon battery chemistries: Foster innovation in low-carbon technologies and circular practices. Further research the climate impacts of emerging ways of raw material extraction, and limit those with significant greenhouse gas emissions.

Bringing battery supply chains to Europe could boost strategic autonomy, avoid the export of European consumption related environmental impacts, and support climate justice - provided that proper environmental safeguards, inclusive planning and transparency are secured.

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