



HAL
open science

When regulations shape the future of an industry, the case of the high voltage battery

Christophe Midler, Marc Alochét

► **To cite this version:**

Christophe Midler, Marc Alochét. When regulations shape the future of an industry, the case of the high voltage battery. *International Journal of Automotive Technology and Management*, 2023, 23 (4), pp.343-382. 10.1504/IJATM.2023.136572 . hal-04303575

HAL Id: hal-04303575

<https://hal.science/hal-04303575>

Submitted on 23 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Christophe MIDLER

Emeritus Research Director

i3-CRG, École polytechnique, CNRS, Institut polytechnique de Paris, Palaiseau

Member of Academy of Technologies of France

Bât. ENSTA – 828 boulevard des Maréchaux – F-91762 Palaiseau cedex France

Email: christophe.midler@polytechnique.edu

Corresponding author

Marc ALOCHET

Associated Researcher

i3-CRG, École polytechnique, CNRS, Institut polytechnique de Paris, Palaiseau

Bât. ENSTA – 828 boulevard des Maréchaux – F-91762 Palaiseau cedex France

Email: marc.alochet@polytechnique.edu

Biographic notes:

Christophe Midler is Emeritus Research Director at the Management Research Center at Ecole Polytechnique, Paris. He is member of National Academy of Technologies of France and Doctor Honoris Causa at Umea University, Sweden. His research topics are product development, project and innovation management. He has explored these topics especially in the automotive industry. Recent co-authored books are *Working on innovation*, (2010) *The Logan Epic ; new trajectories for innovation* (2013), *Managing and Working in Project Society – Institutional Challenges of Temporary Organizations* (2015), *Rethinking Innovation and Design for Emerging Markets, Inside the Renault Kwid Project*, (2017), “*The innovation odyssey, lessons from an impossible project*, (2023).

Marc Alochét is Associated Researcher at the Management Research Center at Ecole Polytechnique. He holds a PHD in management sciences and has a long career in the industry including more than 30 years with a European global automaker where he held different positions in engineering divisions with production engineering as a strong guideline. In the context of the emergence of CASE and Mobility service, his research interests focus mainly on their systemic effects on the architecture of the automotive industry as well as the transition towards new mobility systems. He recently co-authored the book: “*The innovation odyssey, lessons from an impossible project*”, (2023).

When regulations shape the future of an industry, the case of the high voltage battery

Abstract

In China, Europe and the United States, the transition from thermal to battery electric vehicles is ongoing under the effect of technology forcing regulations. We investigate whether and how those related to high voltage batteries could shape the future of the automotive industry. While China is leading the way, Europe and the United States, with very high levels of funding, are racing against time to catch up and develop a sustainable battery value chain controlled by local champions. As the U.S. resorts to protectionism, we hypothesize that we may see the emergence of three geographic production hubs, ending the globalization of the battery industry.

Keywords: High voltage battery, zero emission vehicle, regulation, China, Europe, United States, battery manufacturing, battery supply chain, localization.

1. Introduction

Although the political will to reduce internal combustion engine vehicles (ICEVs) emission levels is long-standing and that, by the early 2020s, over 85% of global car sales are subject to appropriate regulations worldwide (IEA, 2021), a massive and rapid increase in sales of zero-emission vehicles had not yet taken place until recently.

The current fast transition, from ICEVs to electric (battery) powered (BEVs) and plug-in hybrid vehicles (PHEVs), is neither driven by the industry itself nor a consequence of changing consumer expectations: it is a recent, growing and persistent global set of increasingly stringent environmental regulations, resulting from the Paris Agreements in 2015, that force the automotive industry to switch toward electrification (Alochet & Midler, 2019).

2022 results of global light vehicle sales vividly demonstrate this statement. While under the triple effect of Covid-19, supply constraints for semi-conductors and the repercussion from the war in Ukraine (mainly in Europe), markets are contracting again, plug-in vehicles (BEVs and PHEVs) saw a significant 55% increase in sales, compared to 2021, and the predominance of BEVs which could represent 73% of around 40 million light plug-in vehicles in circulation by the end of 2023.

The three main markets for plug-in vehicles, in 2022 and 2021, are respectively China, Europe and the United States¹. However, these are the regions that have enacted the most demanding regulations: Europe and California aim at 100% of zero emission vehicles by 2035, the US federal regulation aims at 50% of zero emission vehicles by 2030² (and 67% by 2032) while China aims at 50% BEV & FCEV, 50% PHEV by 2035³.

It highlights that, innovation, traditionally associated with market competition, is now increasingly "administered" by public policies in the name of societal imperatives. Moreover, in this paper, we take, as our starting point, the influence of public institutions in structuring markets which has long been emphasized by scholars (Fligstein, 1996; Lindblom, 2001; Nelson, 1994). But, the urgency of the climate crisis is leading to an unprecedented level of public policy intrusion into the technological dynamics of the automotive industry. Combined with the centrality and higher price of the high-voltage battery system compared to conventional ICEV systems, this observation leads us to question whether high-voltage battery regulations will shape the future of this industry.

With the exception of very recent studies dedicated to a comparison between China and Europe (Alochet & Midler, 2021; Jetin-Duceux, 2022) or between China and the United States (Klebaner & Ramirez Perez, 2022), most of the literature on the role of regulations in the automotive industry's transition to electrification is limited to studying their effects at the national level and thus lacks comparative studies across countries or world regions (Jetin-Duceux, 2022; N. Wang et al., 2019; Wesseling, 2016).

To fill this gap, we undertake a comparative analysis of US, European and Chinese regulations dealing with the transition toward electrification. This comparison is very interesting because, firstly, the observed regions are very different in terms of political systems and institutions: China has a command economy with an interventionist approach, the European Union is a single economic and political union among 27 countries, while the United States is a federal union of 50 states with a liberal approach to market regulation. Second, while western countries have long dominated the ICEV market, they are now China's challengers in vehicle electrification: by the end of 2021, China has the highest battery manufacturing capacity

¹ All figures from <https://www.ev-volumes.com/>, retrieved on February 6, 2023

² <https://ww2.arb.ca.gov/resources/fact-sheets/governor-newsoms-zero-emission-2035-executive-order-n-79-20>
<https://www.europarl.europa.eu/news/en/press-room/20220603IPR32129/fit-for-55-meps-back-objective-of-zero-emissions-for-cars-and-vans-in-2035>
<https://www.federalregister.gov/documents/2021/08/10/2021-17121/strengthening-american-leadership-in-clean-cars-and-trucks>

³ New Energy Automobile Industry Development Plan (2021-2035)

(655GWh) compared with 57 GWh in the United States and 60GWh in Europe⁴ and, by the end of 2022, is taking the lion's share of sales of plug-in vehicles (see figure below).

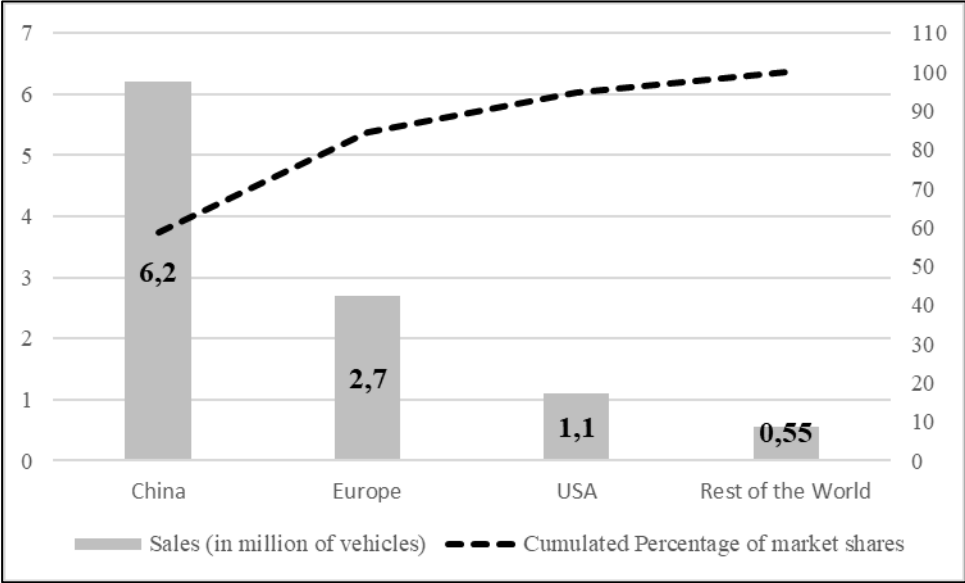


Figure 1-1: Shares of plug-in vehicles sales in 2022 (Source EvVolumes)

This paper is organized in four sections. In Section 2, we explain our process for locating, selecting, collecting and processing data. Section 3 presents the results of our empirical comparison of regulations in the United States, Europe and China. In Section 4, we discuss the use of regulations to manage this transition in each observed region and summarize their impacts on the competitiveness of the industry. In Section 5, we present our conclusions and hypotheses as pertains how (supra-)national regulations might shape the future of the automotive industry.

2. Data Location, Selection, Collection and Processing

The analytical framework of the empirical study consists, for China, Europe and the United States, in: (i) summarizing the overall picture of regulations aimed at reducing pollutants⁵ and CO2 emission levels for personal cars and light-duty vehicles; (ii) focusing on regulations related to high voltage batteries and (iii) analyzing the impacts of these regulations on the future of the automotive industry at the local and global levels.

To obtain the necessary data, we apply a four steps process:

⁴ <https://www.iea.org/reports/global-supply-chains-of-ev-batteries>, issued July 2022

⁵ carbon monoxide (CO), total hydrocarbons (THC), non-methane hydrocarbons (NMHC) and nitrogen oxides (NOX). It also encompasses airborne particles, measured in terms of particulate matter (PM) and particle number (PN). These pollutants can be responsible, depending on the level to which one is exposed, for respiratory problems of varying severity

1. Data location consists in identifying the (supra-)national authorities in charge of promulgating these regulations.
2. Data selection consists of identifying the relevant regulations they have issued. We focus on their objectives (the what) and how they are designed (the how) by looking at two main features of regulation, incentives and financing.
3. Data collection consists in retrieving the selected regulations (and associated reports if any) from the appropriate web sites.
4. Data processing consists in extracting, manually, from the regulations and reports retrieved, information relating to both the quantified objectives and the mechanisms implemented to achieve carbon-free mobility.

Because of the very different institutions in the observed regions, we had to undertake preliminary research to identify the key regulatory organizations involved in this transition. We list them below:

- In China, the National Development and Reform Commission (NDRC, created 2003), whose main mission, related to our study, is national economic development, is a key actor of the electrification of the automotive industry. Other key institutions at the ministerial level that promulgate relevant regulations, on their own behalf or jointly, include the Ministry of Industry and Information (MIIT); The Ministry of Science and Technology (MOST); The Ministry of Finance (MOF).
- The European Commission is organized into policy departments, called Directorates-General (DGs), and we searched for the relevant DGs. DG CLIMA (Climate Action) promulgates regulations addressing greenhouse gas emissions; DG GROW (Growth) deals with industrial policies for the automotive industry, including the reduction of pollutant emissions, while DG ENV (Environment) deals with battery directives.
- Californian regulations are promulgated by the California Air Resources Board (CARB). The Federal standards are promulgated by the United States Environmental Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). Battery policies and incentives are under the responsibility of the US department of Energy.

We summarize, in Appendix 1, the main regulatory organizations, their general and specific areas of competence for our study, as well as the front-end sites providing access to the dedicated sites from which we retrieved the relevant regulations.

3. Three different trajectories for decarbonizing road mobility

3.1. US regulations

Firstly, we remind that, under the section 177 of the US Clean Air Act, the state of California has the authority to enforce its own legislation addressing emissions from ICEVs and each US state can choose to follow the federal or the Californian regulations.

3.1.1. Emission regulations

In California, the political will to fight against air pollution was forged in the 1940s when the Los Angeles area was plagued with smog. California has pioneered regulations, such as those to reduce pollutants emissions in the late 1960s, that were later rolled out worldwide. It continued in the 1990s with the Low Emission Vehicles (LEV) program to reduce pollutant and GHG emissions and the first-ever technology forcing program for Zero Emission Vehicles (ZEV program).

The LEV program is the first regulatory approach that aims to progressively reduce the emission levels of vehicles "on the street" while promoting the development of radical innovations, such as electric vehicles in the early 1990s. To illustrate the difficult beginnings of this program, the first sales target for the major automakers – 2% of ZEV sales in 1998, 5% in 2001, 10% in 2003 – has been modified numerous times to eliminate the intermediate steps and introduce less complex and less expensive ZEVs categories⁶.

Since then, the state of California, even while forced to adapt to the maturity of available technologies, has never given up on the long-term goal: since 2012, LEV and ZEV packages have been integrated into a comprehensive Advanced Clean Car program. The Advanced Clean Cars II rule, adopted in August 2022⁷, defines the trajectory to achieve 100% of sales of ZEVs and PHEVs by 2035.

The evolution of CO₂ target value (in g/km) between 2009 and 2025 for personal cars⁸ and the trajectory to zero emissions vehicles by 2035 perfectly illustrate the strong Californian political will in favor of clean mobility.

⁶ Information retrieved at <https://ww2.arb.ca.gov/about/history> and <https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about>

⁷ <https://ww2.arb.ca.gov/news/california-moves-accelerate-100-new-zero-emission-vehicle-sales-2035>

⁸ Since 2009, the targets were applicable to all types of cars, but subcategories, defined by the vehicle footprint, appeared in 2017. According to their understanding of the regulations, the authors have chosen to present data for vehicles belonging to subcategories they characterize as "Sedan segment C" and "SUV segments D/E". Information retrieved from "The California Low-Emission Vehicle Regulations" amended as of October 1, 2019 accessible at <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/lev-program/low-emission-vehicle-regulations-test>

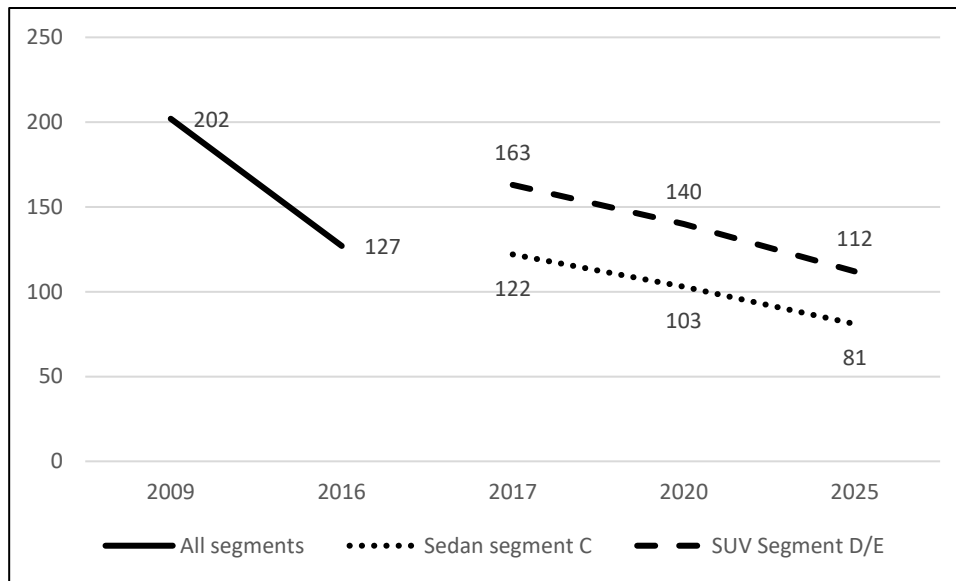


Figure 3-1 : Evolution of Californian CO2 target values for personal cars 2009 – 2025

Source: Authors calculation based on California LEV regulations, amended as of October 1, 2019

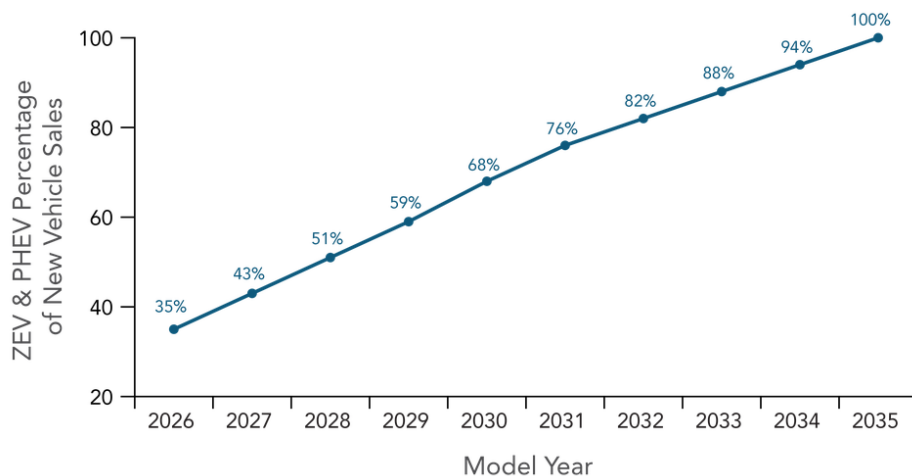


Figure 3-2 : Californian 2026-2035 ZEV and PHEV requirements in percentage of sales

Source : <https://ww2.arb.ca.gov/news/california-moves-accelerate-100-new-zero-emission-vehicle-sales-2035>

As of May 13, 2022, 18 states, accounting for more than 40% of new light-duty vehicle sales in the United States, have adopted or plan to adopt the LEV program⁹. The other states follow the federal regulations which encompass the CAFE (Corporate Average Fuel Economy standards), introduced by the U.S. Congress in 1975¹⁰, and one aiming at reducing GHG emissions introduced under the Clean Air Act in 2011.

⁹ <https://ww2.arb.ca.gov/resources/documents/states-have-adopted-californias-vehicle-standards-under-section-177-federal>

¹⁰ The CAFE, result of a harmonic calculation across all vehicles sold of different models (each having its own fuel efficiency target depending on its footprint) by an automaker, contributes because increased miles per gallon implies lower pollutants emissions (all other things being equal).

At the federal level, the situation is much more chaotic than in California, because there is no political agreement, across successive administrations, on the existence of global warming and the need to reduce pollutants and GHG emissions from ICEVs. We provide here two evidences of this political instability at the federal level.

Firstly, while in 2017, President Obama directed EPA and NHTSA to harmonize the federal GHG and fuel efficiency standards with those developed by California¹¹, the Trump administration suppressed, in 2019, the California state’s authority to enforce its own legislation that the Biden administration recently restored (US EPA, 2022).

Second, the Trump administration enacted the Safer Affordable Fuel-Efficient (SAFE) vehicles rule to go backwards from the emissions requirements set by the Obama administrations, the Biden administration has gone back to what was enacted under the Obama administrations and no one knows what the next administration will be and do!

The evolution of the C02 (in g/km) and the CAFE (in miles per gallon, mpg) compliance targets for passenger cars under four administrations, between 2012 and 2022, as well as projections, respectively through 2028 and 2026, illustrate this “back and forth” movement.

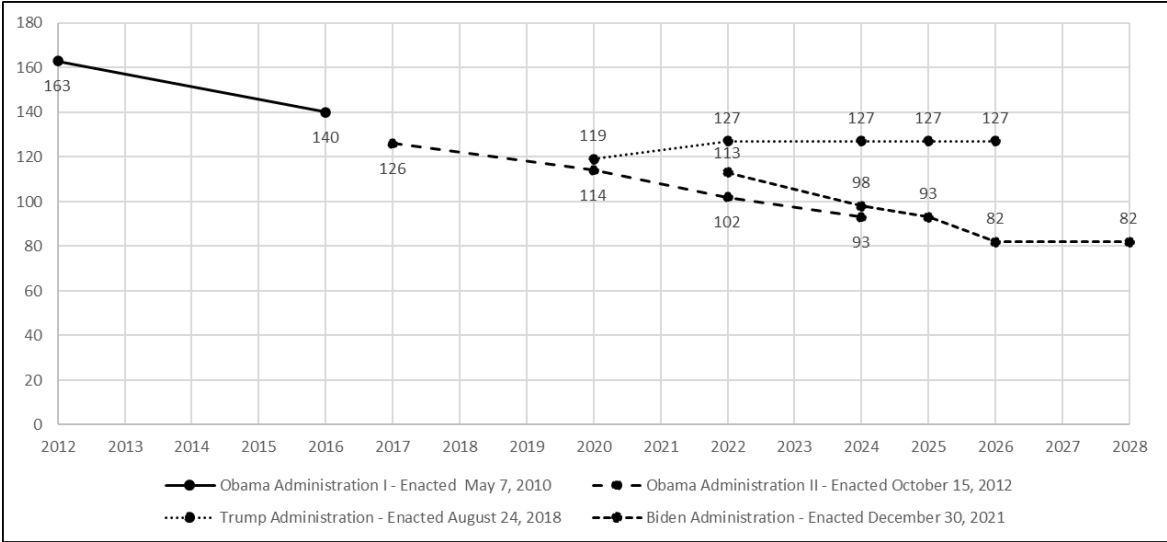


Figure 3-3 : Evolution of EPA C02 compliance target (in g/km) for passenger cars 2012 - 2028

Source: Authors' calculations based on data extracted from EPA regulations enacted at the dates indicated

¹¹ <https://crsreports.congress.gov>

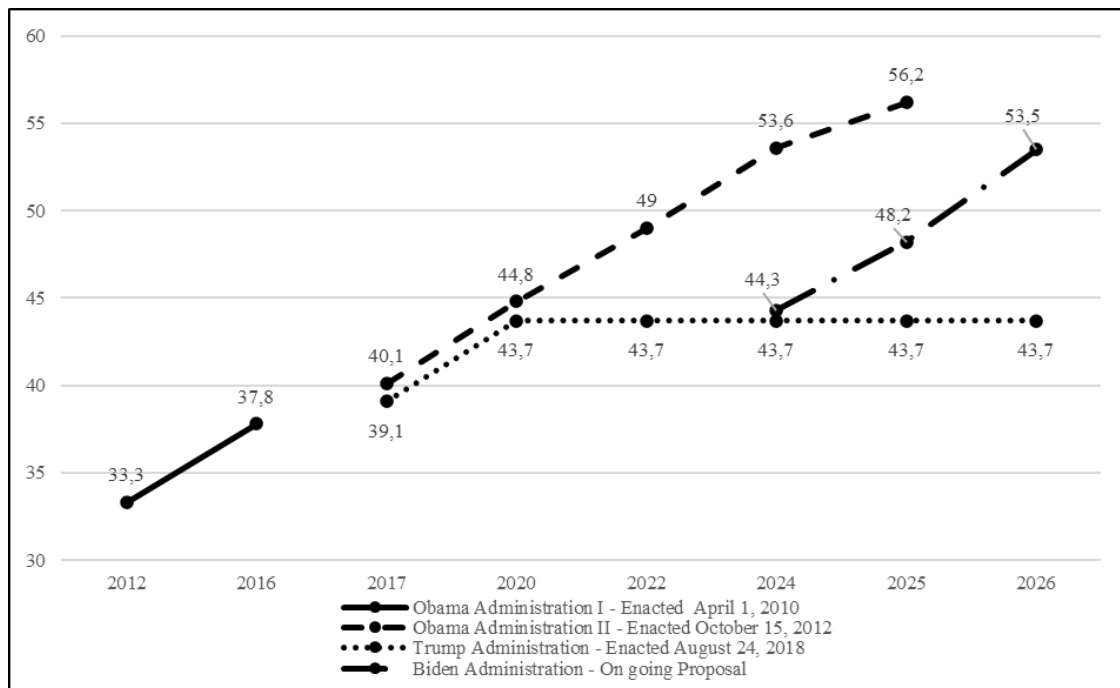


Figure 3-4: Evolution of CAFE compliance targets (in mpg) for passenger cars 2012 – 2026

Source: Authors' calculations based on data extracted from NHTSA regulations enacted at the dates indicated¹²

Executive Order 14037, issued by President Biden in August 2021, aims at 50% zero-emission vehicles for all new passenger cars and light trucks sales by 2030, 67% by 2032 and confirms the current federal administration's commitment to electrification. Indeed, sales of EVs have been tripling in the United States since President Biden took office.

3.1.2. Development of the battery industry

To tackle the absence of mass production capacities in North America, the Department of Energy of the federal government drives the development of the battery industry: among 38 regulations related to “Battery policies and incentives” for electric vehicles, 32 have been enacted or amended at the federal level. The most striking point is that 20 regulations have been enacted under the Biden administration, in only two years since the first regulation was issued on September 10, 2020 (see figure below).

¹² Retrieved from <https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy>

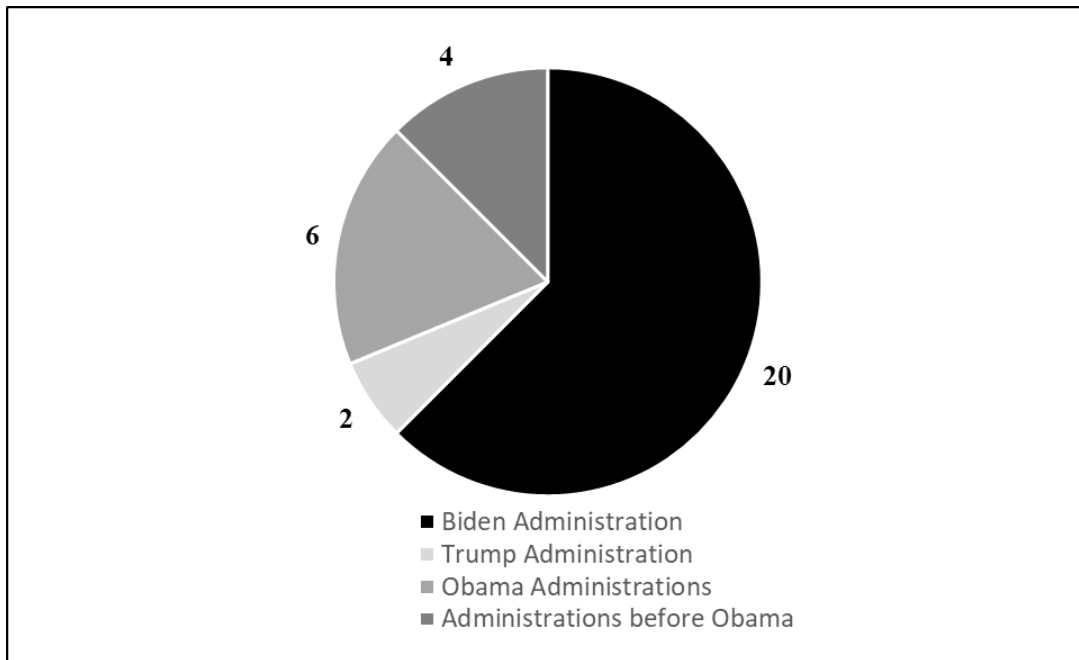


Figure 3-5 : Counts of battery regulations and incentives enacted under Biden, Trump, Obama and prior administrations

Source: Authors' calculations based on data extracted from department of energy website¹³

Our summary, of the 20 regulations enacted under the Biden administration, presents a very comprehensive and consistent plan which encompasses the complete value chain – vehicle, battery and energy technologies development, manufacturing facilities, sustainable domestic battery supply chain, second life and recycling of batteries – including the appropriate funding plans (Appendix 2). Among this comprehensive set of regulations, we emphasize three points:

1. The focus on improving EV performances. The Electric Vehicles for American Low-Carbon Living program provides grants for R&D projects that achieve significant battery performance improvements and cost reduction.
2. A support to manufacturing with a 30% tax credit for project investments to reequip, expand, or establish manufacturing or industrial facility related to energy storage systems and components, electric or fuel cell vehicles and components, grid modernization equipment and components, etc...
3. The strong incitation for battery value chain localization in the United States. The 2022 Inflation Reduction Act¹⁴ amended the Clean Vehicle Credit and added battery requirements beginning January 1, 2023. A vehicle to be eligible must involve local sourcing requirements for critical mineral extraction, processing, and recycling as well as

¹³ Retrieved from <https://www.energy.gov/eere/vehicles/battery-policies-and-incentives-search#/?jurisdiction=US>

¹⁴ Public Law 117-169 enacted on August 16, 2022 by the US congress

battery components manufacturing and assembly. Vehicles that meet critical mineral requirements are eligible for a maximum \$3,750 tax credit, those meeting battery component requirements are eligible for a maximum \$3,750 tax credit which makes a maximum total tax credit up to \$7,500 (progressive increase of tax credit between 2023 and 2029).

4. In addition, the IRA provides tax credit for manufacturing (by the means of the Advanced Manufacturing Production Credit): 10% of the production costs of critical minerals, 10% of the cost of battery electrode active materials, USD 35/kWh for battery cells production, and USD 10/kWh for battery modules production.

3.1.3. U.S.: Comprehensive and relevant policies supported by massive investments

The Biden administration has made a clear commitment to the transition to low-carbon mobility by having the U.S. Congress pass two very important laws - which are part of an agenda that goes beyond the transition to low-carbon mobility¹⁵ - that structure the deployment of current plans and, above all, make it possible to mobilize the funds necessary for their implementation:

- “Infrastructure Investment and Jobs Act” ou “Bipartisan Infrastructure Law” (BIL) - Public Law No 117-58 voted by the US congress on November 15, 2021 with \$7.5 billion in EV charging, \$10 billion, and over \$7 billion in EV battery components, critical minerals, and materials.
- ‘Inflation Reduction Act’ (IRA) already mentioned with nearly \$370 billion in federal funding dedicated to clean energy (in a wide sense).

The successive announcements, in the single year 2022, of an investment of \$5 billion over five years to develop a national EV charging network¹⁶, of a \$2.8 billion funding for domestic battery processing and component manufacturing¹⁷ and of a \$13 billion new financing opportunity for the expansion and modernization of a clean and sustainable national electric grid¹⁸ show that this administration has a deep understanding of the systemic effects that must be mobilized to achieve the transformation necessary to combat the effects of climate change. It also demonstrates a very high capacity to dedicate funds to national priorities and the urgency to act.

¹⁵ President Biden’s “Investing in America agenda” : the Inflation Reduction Act, the CHIPS and Science Act, the Bipartisan Infrastructure Law, and the American Rescue Plan.

¹⁶ <https://highways.dot.gov/newsroom/president-biden-usdot-and-usdoe-announce-5-billion-over-five-years-national-ev-charging>

¹⁷ <https://www.energy.gov/articles/biden-harris-administration-announces-nearly-74-million-advance-domestic-battery-recycling>

¹⁸ <https://www.energy.gov/articles/biden-harris-administration-announces-13-billion-modernize-and-expand-americas-power-grid>

California has had a consistent plan in place for decades which bears fruit: in 2022, ZEVs sales amount to 18,8% of global Californian sales (+ 38% vs 2021) and 40% of ZEVs sold in the U.S. are sold in California¹⁹. To support this rapid transition, Governor Newsom announced, on May 10 2022, a \$10 billion ZEV program to make ZEVs more affordable and to build infrastructure throughout the state²⁰.

Tesla remains the US plug-in vehicles market leader with 65% of the share followed by Ford, Hyundai/Kia and GM²¹. The US incumbent automakers are moving boldly toward electrification: GM plans to sell one million of profitable EVs by 2025, Ford plans to produce two million EVs annually, with 10% operating profit by 2026, and Stellantis plans to sell 50% of BEVs by the end of this decade in the US²².

But it is the strong incentive to localize the battery value chain in the U.S. that is causing the greatest momentum, given the number of battery localization projects already underway or announced: 20 projects of manufacturing or refining are ongoing in 12 states. A total of \$135 billion will be invested to build the future of U.S. electric vehicles, including sourcing and processing of critical minerals as well as battery manufacturing. In addition, private companies have already announced more than \$100 billion in investments in electric vehicles, batteries and electric vehicle charging in the United States (The White House, 2022).

Moreover, in order to produce the EVs they intend to sell, all the US automakers have already set JVs or contracts with Japanese and Korean battery makers for the supply of battery cells or modules for the North American market. They also announce contracts or agreement to supply raw materials or battery components. The largest volumes will be manufactured in factories mostly located in North America, with production starting from 2025 at the earliest (See Appendices 3 and 4 for some examples).

3.2. European regulations

In Europe, the harmonization of emission limits between state members had begun at the beginning of the 1970s (regulation 70/220/EC). The first regulations were promulgated later, with the Euro1 standard for pollutant emissions in 1992, and mandatory CO2 corporate

¹⁹ <https://www.gov.ca.gov/2023/01/20/california-zev-sales-near-19-of-all-new-car-sales-in-2022/>

²⁰ <https://www.gov.ca.gov/2022/05/10/as-statewide-zev-sales-exceed-16-percent-of-all-new-vehicles-california-zev-program-surpasses-250000-point-of-sale-incentives/>

²¹ <https://electrek.co/2023/01/09/the-top-10-best-selling-electric-vehicles-in-the-us-of-2022/>

²² <https://pressroom.gm.com/gmbx/us/en/pressroom/home/news.detail.html/Pages/news/us/en/2022/nov/1117-gm.html>
<https://www.cnn.com/2022/03/02/ford-plans-to-produce-2-million-evs-generate-10percent-operating-profit-by-2026.html>
<https://www.stellantis.com/en/technology/electrification>

standards for passenger cars in 2009, after a voluntary commitment, made by the auto industry in 1998, to reduce emissions had failed to produce adequate results.

3.2.1. Emission regulations

European automakers must meet two regulatory targets for emissions each year: one dealing with CO2 emissions performance requirements, commonly named under CAFE (Corporate Average Fuel Emission)²³, and another one which aims to reduce other pollutant emissions, currently Euro6d.

The European Commission has constantly and steadily reduced the thresholds for CO2 and pollutants emissions since their implementation. The figure below shows the evolution of the CO2 emission threshold, in g/km, from 130 in 2015 to 0 in 2035 when the joint proposal made in 2021, by the European Commission and Parliament, was finally accepted on October 28, 2022 by the European Council and Parliament (European Commission, 2022a).

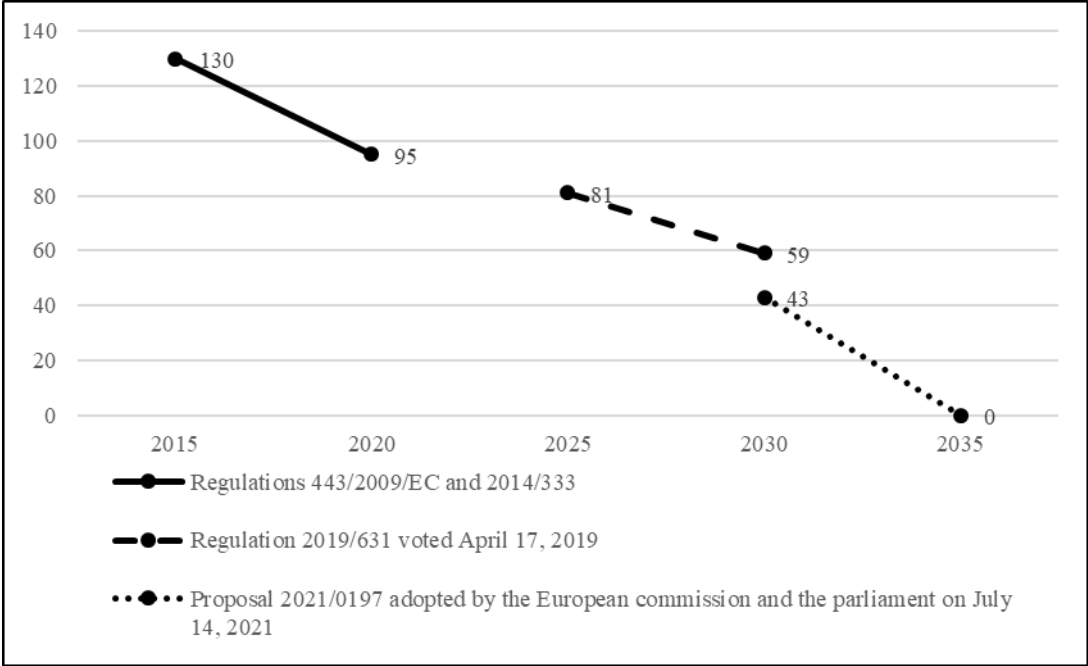


Figure 3-6 : Evolution of CO2 emission threshold for passenger cars in Europe 2015 – 2035 (source: Authors’ research)

The figure below illustrates the drastic reduction applied to the NOx threshold for newly registered cars between Euro1 and Euro6 standards.

²³ Calculated annually as the average of the CO2 emissions of the vehicles sold by an automaker. Regulation 443/2009/EC

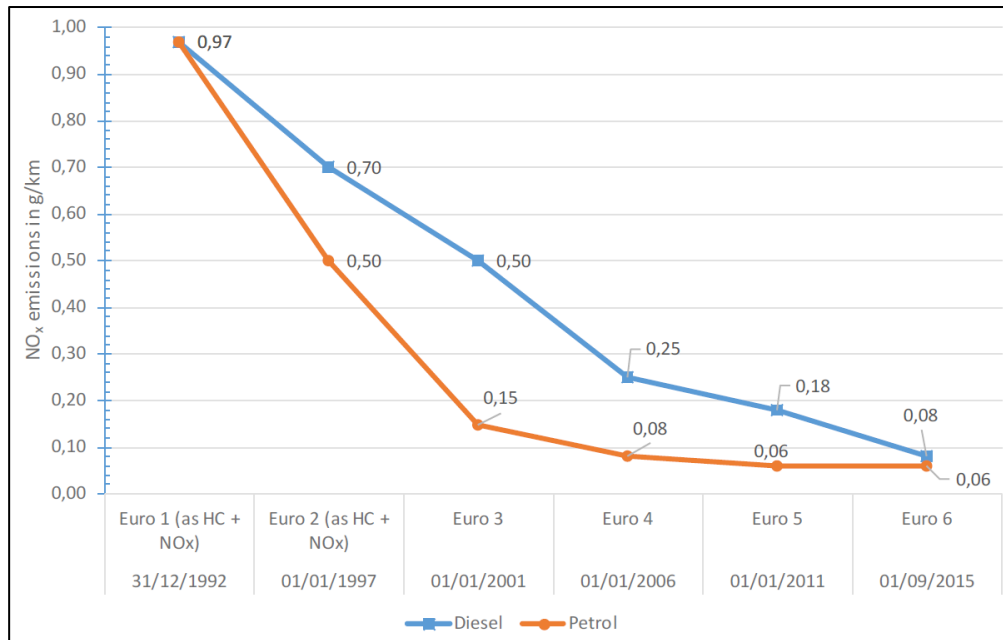


Figure 3-7 : Evolution of the Maximum NOx Thresholds for Diesel and petrol Passenger Cars (in %)

(Source: ECA based on EU regulations)

Despite these very stringent regulations, large discrepancies have been found between the theoretical NOx emissions from diesel vehicles, derived from regulatory compliance results, and actual in-use emissions (See Weiss et al., 2011). In the context of the “Dieselgate” scandal²⁴, which came to light in 2015, the Commission has accelerated initiatives already underway (ECA, 2019), leading to the addition of two complementary measures to the existing schemes:

1. The Worldwide Harmonized Light Vehicles Test Procedure²⁵, applied since September 2017 for new models, aims at ensuring that the test cycle carried out in the laboratory is as representative as possible of the real conditions in which vehicles are used.
2. The Real Driving Emissions test procedure²⁶, applied to all vehicles since September 2019, supplements laboratory measurements with measurements in real road conditions to check that the level of NOx and PM emissions remains within acceptable limits.

Lastly, the Commission published, on November 10, 2022, its final proposal for regulations limiting pollutant emissions (Euro7) which should apply to new vehicles sold from January 1, 2025, regardless of fuel type (European Commission, 2022b). Compared to the Euro6 in-force regulation, the thresholds and control conditions for already tested pollutants are again

²⁴ Volkswagen applied the emission reduction devices only in the regulatory driving situation, leading to non-compliance in the real driving situation.

²⁵ 2017/1151/EC—WLTP, which replaces the New European Driving Cycle (NEDC)— Directive 70/220/EEC.

²⁶ 2018/1832/EC—RDE

tightened, while the scope is extended to brake and tire emissions, the durability requirement is extended by 20% and Minimum Performance Requirements for battery durability are set for hybrid vehicles.

3.2.2. Development of the battery industry

To tackle the lack of mass production capacities and European companies capable of operating them, the Commission launched the European Battery Alliance (EBA) project at the end of 2017²⁷. This program aims to develop an innovative, competitive, and sustainable European battery value chain. With a budget of €100 billion, it brings together national and local public authorities, scientists, research institutes and industrial partners from many countries. In 2018, six strategic priorities, including, among others, secure access to raw materials, support for European battery manufacturing through investment, accelerated R&D plans and the development of a skilled workforce have been defined.

As a result, two batches of Important Projects of Common European Interest, addressing raw materials, cells and modules, battery systems and repurposing, recycling and refining processes, have already been approved by the Commission: one in 2019 with €8.2 billion (total public and private funding) and one in 2021 with €12 billion.

The Commission presented, on December 10, 2020, a new draft legislative framework to replace the in-force Battery directive (2006/66/EC)²⁸. On 22 February 2022, the European Parliament delivered its report (A9-0031/2022) on the proposed regulation and on 18 January 2023, the representatives of the three institutions (Commission, Council, Parliament) formalized a compromise proposal (Final compromise text of the trilogue agreement on batteries) which now has to be voted on in the plenary session of the Parliament before its final adoption. The underlying motivation is the strategic imperative to produce batteries, in Europe, for electric vehicles in the context of the clean energy transition. Among all the proposals, we focus on the following points:

1. Minimizing the carbon footprint throughout the overall battery life cycle, from the extraction and refining of raw materials, the manufacturing of battery pack components and the pack itself, to its dismantling and recycling. At the latest, 18 months after the final adoption of the regulation, a carbon footprint declaration is mandatory to allow a battery to be placed on the market and will be complemented over time by the setting of carbon footprint performance classes and maximum threshold values.

²⁷ https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-battery-alliance_en

²⁸ https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312

2. Battery recycling efficiency with thresholds of 65% by average weight by January 1, 2025 and 70% by January 1, 2030.
3. Material recovery obligation for cobalt, copper, lead, lithium and nickel with two deadlines: by January 1, 2026, 35% recovery of lithium and 90% for the others; by January 1, 2030, 70% recovery of lithium and 95% for the others. It is combined with mandatory reporting of overall recycled content in 2025 to be followed by mandatory recycled content targets for lithium, cobalt, nickel and lead in 2030 and 2035.
4. Finally, the regulation includes, in 2025 as a first step, an information obligation about performance and durability requirements of industrial rechargeable batteries; the setting of relevant minimum values will only be required when more information is available.

These measures will force battery makers to reduce their carbon footprint, which is also a way to force the automotive industry to (re)locate the battery value chain in Europe and avoid the risk of the so-called circular economy rebound effect²⁹.

3.2.3. Europe, the fastest transition to vehicle electrification

Europe is the only region in the world proposing such a fast and radical transition to electrification, leaving only 20 years to the industry to reduce CO₂ emission level, from 130 g/km of CO₂ in 2015 to 0 g/km of CO₂ in 2035.

Major European automakers, all ranked in the 10 first groups in terms of EV sales (see Appendix 7), keep on accelerating their transition to electrification. For instance, VW, which announced a €35 billion investment in electric mobility, and aims at selling 3 million pure electric vehicles per year by 2025, Renault Group electrifying all new passenger car models by 2025 or Stellantis setting the course for 100% of sales of BEVs in Europe by the end of the decade³⁰.

One of the most visible results, so far, of the European Battery Alliance is the creation of the Automotive Cells Company in early 2020, which Mercedes-Benz joined in 2021³¹. In addition, the Swedish company Northvolt has just started production of its first Gigafactory (Northvolt, 2021), and numerous projects to create battery factories are underway, such as those led by Verkor in France. German automakers were the first to announce that they would be

²⁹ The rebound effect of the circular economy would occur if raw materials recovery and recycling operations had a higher environmental impact than the traditional supply chain

³⁰<https://www.volkswagenag.com/en/group/e-mobility.html>

<https://www.renaultgroup.com/en/our-commitments/respect-for-the-environment/>

<https://www.stellantis.com/en/technology/electrification>

³¹ ACC, originally created as a 50/50 joint venture between Saft (a subsidiary of Total Energies) and the PSA Group (now Stellantis), was recently joined by Mercedes-Benz (as of September 24, 2021), with the three partners sharing the capital equally

locating factories, as close as possible to their vehicle assembly sites, to assemble batteries from cells currently still mainly supplied by Asian suppliers. They have since been joined by Stellantis and Renault Group, and the combined production of all these Gigafactories should exceed 600GWh by 2030. This is an undeniable success in terms of production localization, largely driven by automakers to meet their sales objectives of plug-in vehicles imposed by the regulations. They have also initiated contracts with European battery components and raw materials producers to localize their upstream value chain (See Appendices 5 and 6 for some examples).

The draft proposal to replace the battery directive is still in discussion, but we already observe that European battery makers aim at reducing their carbon footprint. For instance, Northvolt aims at an 80% lower carbon footprint compared to those using coal energy by 2030 or ACC whose ambition is to have a supply chain that is at least 70% European by the middle of the decade (ACC, 2023; Northvolt, 2023). In addition, four of the major actors of this emerging industrial ecosystem (ACC, Northvolt, Verkor and InnoEnergy) give their full support to the Commission proposals and wish their rapid implementation (Verkor, 2022).

3.3. Chinese regulations³²

The first-ever mandatory fuel economy standard (GB 19578-2004) for passenger vehicles in China, implemented in 2005 for new models, stipulated that each vehicle model must comply with fuel economy rules before it is marketed. The Corporate Average Fuel Consumption (CAFC) standard (GB 27999-2011), similar to the US CAFE in terms of effect on emissions and calculated by averaging the actual fuel consumption of vehicles sold by an automaker, was enforced in 2012 and coexists with the per model fuel consumption rule.

3.3.1. Emission regulations

The regulation known as the “dual-credit policy” – latest revision in force since January 1, 2021 –, stipulates that, automakers, above a threshold of 30,000 vehicles manufactured or imported must comply with two targets, the first being the CAFC.

The figure below shows the stiff reduction of the maximum CAFC threshold imposed to automakers: - 40% in less than 10 years!

³² The authors warmly thank Xieshu Wang for her great help in searching and translating Chinese data supporting the study

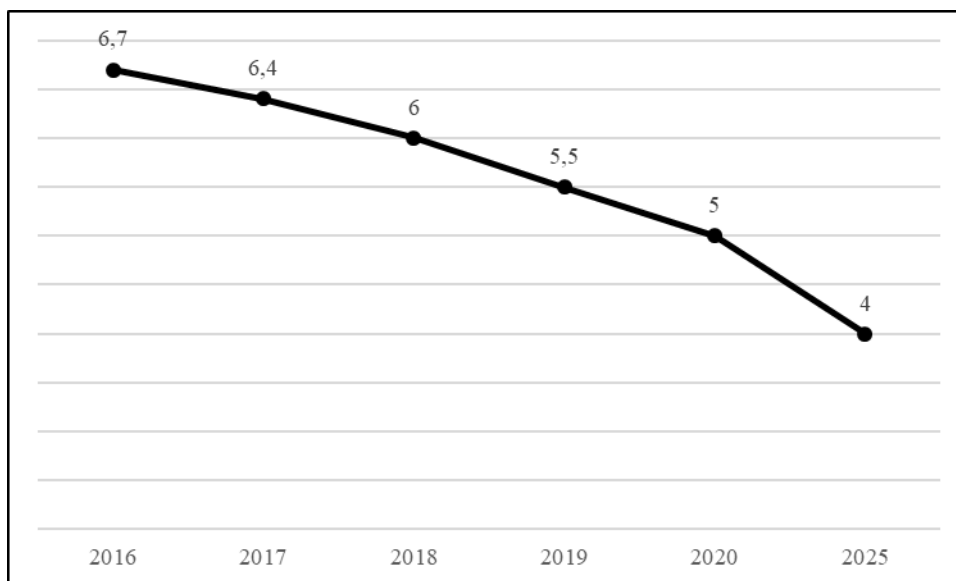


Figure 3-8 : Change in CAFC Between 2016 and 2025 (in l/100km) (Source: Authors' research)

The regulation "Electric Vehicle Energy Consumption Rate Limit", (GB/T 36980-2018) applicable since July 1st, 2019, is the first regulation in the world that sets consumption thresholds (in kWh/100 km) for battery-powered vehicles according to their mass (below 3500 kgs). Compliance with this regulation is mandatory before a battery electric vehicle can be put on the market. It defines a grid of thresholds in two stages: for the first stage, the consumption is calculated according to the standard "Electric vehicles - Energy consumption and range - Test procedures" (GB/T 18386-2017) which uses the NEDC cycle. For the second stage, the standard "Test Methods for Energy Consumption and Range of Electric Vehicles - Part 1: Light Duty Vehicles" (GB/T 18386.1-2021) applies from 1 October 2021. It uses the Chinese Automotive Test Cycle (CATC) which is (fairly) similar to WLTP.

The NEV credit (New Energy Vehicle)³³, which does not exist in Europe or the United States, is the second mechanism implemented to support this trend toward zero-carbon vehicles.

For every NEV model put on the market, the NEV credit is calculated according to a formula involving the following criteria: range, battery energy density (a key parameter of battery performance) and vehicle energy efficiency (a parameter that influences battery operating performance and vehicle design)³⁴. Because the NEV credit can be greater than 1, it is not a sales target: it encourages manufacturers to develop increasingly efficient EVs, and thus, stimulates the competitiveness of the Chinese electric vehicle industry.

³³ A manufacturer producing only electric vehicles is only concerned with the NEV credit.

³⁴ For more information on the detailed calculation of the NEV credit, see Chen, Z., and He, H. (2021)

The strengthening of the NEV credit target also occurred very quickly, as illustrated in the figure below.

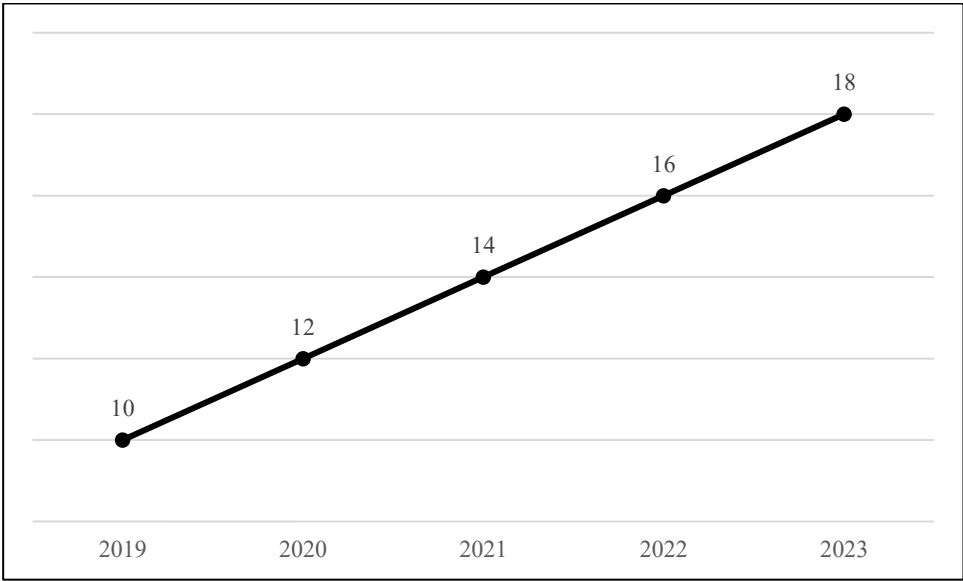


Figure 3-9 : Change in NEV Credit Requirements Between 2019 and 2023 (in Percentage) (Source: Authors' research)

The traditional role of subsidies is to encourage demand by making the product more affordable to buy and/or use. While the strategy adopted by the Chinese government was initially aligned with this conventional approach, it is now also a way to improve the performance of a vehicle, as it is done on the supply side. This approach is remarkable in the consistency of the criteria used to calculate the NEV credits and the level of subsidy allocated to a given model. Indeed, without going into detail, we find for the latter the criteria of range, battery energy density and vehicle energy efficiency, to which is added a criterion related to the size of the battery.

Consequently, automakers have a double incentive to increase the performances of all their vehicles: one is mandated by regulation and leads to NEV credit purchases from other automakers if CAFC and NEV credit targets are not met, and the other, as a result of market competition, leads to an EV being price uncompetitive if its performance does not make it eligible for subsidies.

3.3.2. Development of the battery industry

Since the very beginning of Chinese electric vehicles industry, in the 2000s, the development of power batteries was identified as a strategic technology for the future of this industry and was allocated , in the framework of the Program 863, significant R&D funding under the leadership of the MOST (Liu & Kokko, 2013).

Since then, the development of China's battery industry has been strongly guided and supported, at a rapid pace, by regulations as shown below:

1. In 2012, the MIIT outlines the conditions for any company wishing to be part of the newly created NEV industry, in terms of design and production capacities as well as compliance to international quality standards. In addition, for the battery industry, it provides some ambitious targets, for a newly created industry, such as a gravimetric energy density of 180 wh/kg at the cell level in 2015.³⁵
2. MIIT, considering the highly dispersed development level of the battery industry that limits the expansion of the overall NEV industry, introduces in 2015, the "Automotive Power Battery Industry Standard Conditions" to further standardize the power battery industry³⁶.
3. At a time when Japanese and Korean battery manufacturers are far outpacing Chinese newcomers, MIIT introduced the 'Regulations on the Standards of Automotive Power Battery Industry' catalog in 2016, which restricted the awarding of subsidies to only vehicles with batteries produced by the listed Chinese companies (X. Wang et al., 2022).

In parallel, thanks to high level of funding from national, regional and even local public authorities, new production capacities were launched and commissioned. Consequently, China surpassed the production capacity of both Japan and Korea probably in 2015 (IEA, 2020).

Regulations continue to strongly guide the development of the battery industry by the means of subsidies for purchasing EVs and the NEV credit (there are some performance criteria for the battery), the promulgation of "Automotive Power Battery Product Inspection Standards Catalogue"³⁷ in 2016, the "Action Plan for Promoting the Development of Automotive Power Battery Industry"³⁸ in 2017 to cite but a few.

The first regulation addressing the issue of battery recycling was promulgated by the NDRC in 2016³⁹ and has been regularly supplemented and expanded, with the latest document being "China's 14th Five-Year Plan for Circular Economy Development" released mid 2021 by the NDRC.

³⁵ Notice on Organizing the Application for the 2012 New Energy Automobile Industry Technology Innovation Project - - Public Finance Project [2012] No. 141.

<http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757018/c3757483/content.html>

³⁶ <http://www.miit.gov.cn/n1146295/n1652858/n1652930/n4509627/c4511776/content.html>

³⁷ Supplementary Notice on Enterprise Declaration in Accordance with the "Regulations on the Standards of Automotive Power Battery Industry" – MIIT April 29, 2016

³⁸ <http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757018/c5505456/content.html>

³⁹ Electric vehicle power battery recycling technology policy - <http://zfxgk.ndrc.gov.cn/web/iteminfo.jsp?id=2389>

3.3.3. China has achieved a significant step in mass-production of plug-in vehicles

When the electric car emerged in the early 2010s, China had already become a volume giant in the global automotive industry but suffered from its technological dependence on foreign automakers and suppliers. For Chinese automakers, struggling to compete with the global competitors in the ICEV market, vehicle electrification was an opportunity to catch up with them.

In 2015, the Chinese government released the document "Made in China 2025" which aims both to increase the competitiveness and global market share of Chinese manufacturing and to reduce China's dependence on foreign countries for manufactured goods. This report notes that the Chinese manufacturing industry is certainly important in volume, but does not reach the best levels of competitiveness of global competitors. Therefore, the plan aims to drive the transition from "Made in China" to "Created in China" by, among other strategies, shifting the manufacturing industry "from big to strong". The automotive industry was to follow this, that accelerated the rise of the EV industry in China.

This effort is continuing as the NEV industry is one the "strategic emerging industries" that China is strongly promoting in the 14th Five-Year Plan (2021-2025). China, today, is the first producer of plug-in vehicles and HV batteries, has the biggest stock of electric vehicles in operation and has a significant market share of almost 59% in 2022 with BYD leading the plug-in vehicle market⁴⁰. Geely takes the 8th position and, thanks to their huge domestic market, Chinese automakers monopolize almost all the places from the 11th to the 20th position, with only Ford managing to squeeze in between them.

There are four main factors to explain this result. First, the impetus given by the central government for automakers to improve the electric range + battery power + energy consumption tripod played an important role in the increase of performance of BEVs (Muniz et al., 2019) which favored the take-off of sales.

Second, China has created a new industry, namely New Energy Vehicles (NEV), capable of mass production as evidenced by the following data:

1. By mid-2017, 15 NEV production permits had been granted by the NDRC for an annual production capacity of 865,000 vehicles and an initial investment equivalent to €3.2 billion⁴¹.

⁴⁰ Tesla is leading if only BEVs are considered, see Appendix 7

⁴¹ Search realized by the authors based on production approvals issued by NDRC between March 2016 and May 2017

2. In 2019, 500 NEV manufacturers were registered in China in 2019, of which 60 had presented at least one vehicle concept (Song & Suzuki, 2019).

Third, the start of mass production of plug-in vehicles happened in China in 2017, much earlier than in Europe and United States where sales really took off in 2020 and 2021 respectively.

Lastly, according to the International Energy Agency (2022, p. 31), “China dominates the entire downstream EV battery supply chain” with 76% of battery cell manufacturing capacities, 70% for cathode, 85% for anode, 80% for graphite mining and refining. Wang et al. (2022) explain how Chinese battery makers have developed a “specialized vertical integration” strategy to develop the most comprehensive battery value chain in the world which dominated the market. This strategy consists in both continuing to reinforce their existing capacity using specific established assets in their original segment of the value chain, and actively entering related upstream and/or downstream segments. In addition, major players have acquired mining resources, often from abroad, with the intention of minimizing the risks of raw material supply and price volatility.

4. Discussion

First, we address how China, Europe, and the United States manage the transition toward electrification and, second, we summarize how regulations may impact the competitiveness of the battery industry in each region.

4.1. China, Europe, the United States, contrasting modes of intervention

4.1.1. China: The Implementation of an “Administered Darwinism”

After the failure to reach the goal of 500,000 electric vehicles sold in 2011, public authorities have made four major inflections to allow for a very rapid scaling up of electric vehicles. The first was in 2012, when it was decided that battery electric vehicles would be the strategic priority (Yuan et al., 2015).

The second inflection came from the continuous tightening, since 2014, of the criteria for obtaining subsidies⁴² and then the creation of the NEV credit (2016), both of which were pushing for the mass development of electric vehicles increasingly efficient in all aspects of design.

⁴² See Appendix 8 for the list of regulations dealing with successive tightening of criteria for obtaining subsidies

Two other recent inflections also show a pragmatic adaptation of regulations to market realities. While the purchase subsidies were to disappear at the end of 2019 to eliminate the weak manufacturers unable to meet the growing demands of the market, the third inflection led to their extension until the end of 2022⁴³. This was to consider the downturn in the overall Chinese car market, the impact of COVID-19, and the need to support NEV sales.

In 2019, the faster-than-expected increase in BEVs range, due to technological progresses, produced a surplus of 3.31 million NEV credits. As this did not push automakers to improve ICEVs or accelerate the improvement of EVs, a fourth inflection took place very quickly, at the very beginning of 2021: the tightening of the dual credit policy introduced a new hardening of the consumption thresholds associated to weight curb, a significant reduction in the CAFC to 4L/100km by 2025, as well as new and even more restrictive criteria for achieving the NEV credit target.

In addition, very voluntarist decisions, including legislative barriers to the entry of foreign products, supported by high level of funding have allowed the very rapid development (less than 20 years) of a Chinese battery industry that now completely dominates this nascent industry.

Midler and al. (2021; 2023) have coined the term “Administered Darwinism” to describe the Chinese governance of this transition. We synthesize the main characteristics as follows.

1. The Chinese government exercises its dirigiste role in the economic world with a very strong capacity to intervene over a large scope at whatever the cost.
2. It has given itself the means to be competent over the entire industrial perimeter and can intervene from key components to the final car in an appropriate and intrusive way. As a result, it not only sets objectives but also dictates how they are to be achieved, for example by making cars lighter or improving battery density to increase energy performance.
3. The public authorities develop massive aid upstream, on the basis of promises of performance, initially uncertain. And then, they quickly and deeply evaluate the performances achieved by the professional actors, eliminating those who do not correspond to the desired trajectory, and reinforcing the required criteria in view of the performances observed by the best.
4. Finally, it is constantly adjusting regulations, even if it means making pragmatic short-term deviations, depending on whether (future) industrial champions achieve the set targets or not.

⁴³ Notice on improving the financial subsidy policy for the promotion and application of new energy vehicles - http://www.gov.cn/zhengce/zhengceku/2020-04/23/content_5505502.htm

An emblematic example is the tightening of the CAFC and NEV credit criteria, which was carried out because the results observed did not correspond to the desired trajectory.

This Chinese-style “Administrated Darwinism” thus combines in an original way the classic features of dirigisme in socialist economies and those of Californian venture capitalists.

The result is an impressive sectoral learning capacity highlighted by the rapid selection of Chinese champions (see figure below) with the level reached in a few years by the Chinese electric vehicles. On the other hand, their performance has significant sunk costs related to the players who have disappeared in this race.

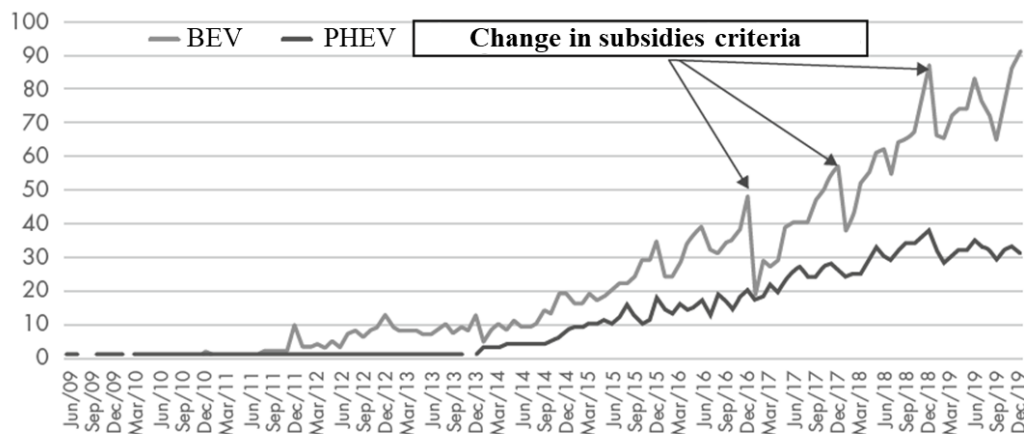


Figure 4-1: Evolution of the number of BEV and PHEV models according to the increasing severity of the subsidies criteria
Source: Midler et al. (2023, p. 123)

4.1.2. In Europe, a rapid switch to a technology forcing transition

The development of regulations, focused on the reduction of CO2 and air pollutant emissions, was designed with a certain sense of inevitability: the political institution let the incumbents - the automakers which, represented by ACEA⁴⁴, have been part of a shared governance of emissions regulation since 1993⁴⁵ (Akpinar, 2017) - decide on the feasibility of the proposed evolution based on the technologies they were likely to develop in continuity with those they already mastered.

The strategy was therefore to accompany the progressive transition trajectories of automakers by providing a stable framework of objectives, guaranteeing fair competition while maintaining technological neutrality on the means of achieving them: this is typical of what Weible and Sabatier (2018) describe as a “classical incremental model.”

But under pressure from public opinion and Non-Governmental Organizations, fueled by the fight against global warming and the Volkswagen's "Dieselgate," things have changed and

⁴⁴ The European Automobile Manufacturers’ Association, or ACEA, unites Europe’s 16 major car, truck, van and bus makers

⁴⁵ Directive93/59/EEC

Europe pivoted, in 2015, to a strategy of technology forcing. The recent decision to make all new cars (and vans) registered CO₂-free by 2035 and the proposed Euro7 regulations are changing the game and leaving the industry with no choice but electrification (Pardi, 2021).

Consequently, this strong and quick shift in favor of battery-powered vehicles provoked very strong reactions from both the European, via ACEA⁴⁶, and particularly the German automotive industries via the VDA⁴⁷. They both denounced an abandonment of the shared governance of emissions regulations, of technological neutrality as well as a strong increase in cost for customers and the incapacity to achieve expected targets in time.

In fact, under the threat of heavy penalties for not meeting CO₂ targets⁴⁸, automakers have had to change their strategy: now, they all offer plug-in vehicles, even though their full range of models of BEVs will probably not be on the market until 2024.

In the field of the battery industry, Europe also wants to achieve very ambitious objectives by 2030, since it is a question of developing local champions capable of implementing a value chain with a low carbon footprint and allowing for very high recycling and reuse rates of raw materials. If the objectives are still very stringent, the method used allows time for capitalization to set the thresholds to be implemented and, above all, the proposal has received a favorable reception from the European actors of this new ecosystem who see the possibility of a rapid and ambitious development. Here, the Commission, without losing sight of the final objectives, is more in its historical mode of governance of environmental regulations.

The impetus given by the European Commission to the development of an efficient and sustainable European battery value chain is considerable, both in terms of the amount of investment planned (€500 billion by 2030 to achieve self-sufficient production) and the core competencies involved in 111 projects so far. But the ambitions are also considerable, since Europe wants to be able to cover its battery needs to the tune of 69% and 89% by 2025 and 2030 respectively.

However, the rise of European automakers toward electrification, which has been made possible by the location in Europe of Gigafactories operated largely by Asian battery

⁴⁶ <https://www.acea.auto/press-release/fit-for-55-eu-auto-industry-initial-reaction-to-europe-climate-plans/>
<https://www.acea.auto/press-release/new-euro-pollutant-emission-proposal-risks-slown-down-transition-to-zero-emission-transport/>

⁴⁷ https://www.vda.de/en/press/press-releases/2021/210617_EU-obviously-wishes-to-stop-embracing-all-technologies
https://www.vda.de/en/press/press-releases/2022/221110_PM_Euro-7_emissions_standard_Commission-s-proposal-cannot-be-implemented-on-schedule-by-industry--imminent-cost-explosion-for-consumers

⁴⁸ The penalty applied, calculated by multiplying the number of grams of CO₂ in excess (on average on the vehicles sold) by the number of vehicles sold and by the amount of the penalty applied to an excess of one gram—i.e., €95 can quickly reach several hundred million euros!

manufacturers, is a double-edged sword: Benchmark Mineral Intelligence, quoted by Reuters⁴⁹, estimates that by 2031, only 43% of production will be by European manufacturers, with the remaining 57% by Asian manufacturers, split between 44% for Asian battery makers' own facilities and 13% for Tesla's German factory that BYD is likely to supply⁵⁰. The situation is probably similar for the upstream value chain even if many projects, involving European companies to address raw materials sourcing and refining or the production of battery components, are launched in numerous European countries (EBA 250, 2021).

4.1.3. The United States: decisional heterogeneity at the state level and policy instability at the federal level

Decisional heterogeneity at the state level is not new, as the state of California was allowed in 1970 to set its own separate regulations, more stringent than federal's ones. Automakers, producing or selling in the United States, are used to dealing with this system of double regulation. The Biden administration's convergence on ambitious electrification targets may help to mitigate this heterogeneity, as it did, during the Obama administrations, when California and federal regulations were harmonized.

The major risk for the future of the automotive electric industry is the political alternation as (i) that could call into question a long-term strategy, as illustrated by the recent back-and-forth movement, between the Trump and Biden administrations, and (ii) could delay automakers' commitments to medium/long-term technological developments and downgrade their offerings in Californian and foreign markets with highest level of electrification requirement. It also calls for both electrification and legislative consistency in the US, when, at the same time as the Trump administration promulgates the SAFE rule, GM calls for a National Zero Emission Vehicle (NZEV) program with ambitious targets (General Motors, 2018). GM is an example of an incumbent automaker that understands the global advantages of moving to electrification on the long term despite what the current administration says.

The solutions implemented in the United States, to catch up with the Chinese leadership in the battery value chain, show similarities with those implemented in Europe: (i) huge level of funding to support comprehensive action plans based on strong science and technology expertise; (ii) technology-forcing strategy, for a long time in California and more recently at the US federal level; (iii) all American automakers have already concluded either long-term partnerships or JVs with Asian manufacturers for the supply of the cells used in their US battery

⁴⁹ <https://www.reuters.com/technology/europe-leans-asia-homegrown-ev-batteries-2022-11-03/>

⁵⁰ <https://batteryindustry.tech/tesla-starts-utilising-byd-batteries-at-giga-berlin/>

packs manufacturing operations; (iv) many projects involving (north) American companies are launched to address the upstream operations of the value chain and, (v) the dependence of U.S. automakers, until about the middle of this decade, on Asian battery manufacturers could jeopardize the rapid emergence of a localized value chain⁵¹. However, we don't observe any announcement (yet) of a battery Gigafactory operated by a North American company using its own technologies.

In addition, the current administration is skillfully using the common will of successive U.S. administrations (both Democrat and Republican) to develop jobs and profits for industry to secure investments in a bipartisan logic as evidenced in this quotation: “These new actions – paired with the investments in the President’s Build Back Better Agenda – will strengthen American leadership in clean cars and trucks by accelerating innovation and manufacturing in the auto sector, bolstering the auto sector domestic supply chain, and growing auto jobs with good pay and benefits” (The White House, 2021).

4.2. Has the automotive industry's competitiveness changed sides?

If the state of California has pioneered, since the 1990s, with many difficulties, the development of zero emission vehicles, Europe has waited till 2015 to firmly engage the move toward electrification and the US federal state, because of the lack of political consensus across successive administrations, has committed to electrification only by 2021. And still, these regulations, until the beginning of the 2020s, only concerned the vehicle!

As already evidenced by Klebaner and Ramirez Perez (2022), one must acknowledge that Europe and the United States (as a whole) have not taken advantage of their expertise resulting from a long experience of regulation of the automotive industry to anticipate the transition to decarbonized mobility and to produce regulations dealing with the systemic innovations that this transition requires.

The rapid scale-up of the NEV industry leading to China’s current domination on the automotive industry turned-electric is therefore a combination of the lack of appropriate regulations in Europe and in the United States and of focused Chinese regulations⁵²: we can state that regulations shape the future of the industry. We now move one step further and try to

⁵¹ Tesla, in the “Impact Report 2021”, explains that the company is committed to improve the traceability and sustainability of its battery supply chain. However, in this report, the current supply chain for extraction and refining (see p 103) appears to be mainly located out of North America which demonstrates the difficulty, even for a first mover, to achieve such a result.

⁵² The authors don't underestimate the importance of three other keys factors: a strong political will to assert the dominance of the Chinese electric car industry, a systemic approach encompassing the complete value chain as well as huge funding at national, regional and local levels.

assess how deeply the Chinese regulations influence the competitiveness of the western automotive industries.

Chinese ICEVs have never really been in capacity of challenging Western models. But now, NIO, SAIC and Xpeng, to cite but a few, offer BEVs that are perfectly capable of attracting Western customers. MG, subsidiary of SAIC, has sold more than 100 000 EVs in Europe in 2022. The latest model, the MG4, which was awarded Five-star Euro NCAP⁵³ safety rating, has prices starting from € 28,990 while competitors (Renault Megane e-tech or VW ID3) have starting prices over € 37,000⁵⁴. In a context of forced transition where the prices of their models do not make them accessible to the greatest number of customers (with the exception of Dacia Spring in Europe), Western mass-market automakers could quickly find themselves in difficulty in the face of growing and very attractive offers from Chinese NEV makers. The situation is probably less critical in the United States than in Europe where " Preserving and promoting fair competition practice " remains a very strong pillar of the EU competition rules.

This increased competitiveness of NEV Chinese models (probably not all yet today) puts a pressure on western automakers to rapidly improve the ratio cost / performance of BEVs. If the United States resort to protectionism – as president Biden signed a determination permitting the use of the Defense Production Act⁵⁵ – to tackle this issue, we don't observe yet any propositions of regulations in Europe to achieve such targets in both short and middle terms.

As far as HV batteries are concerned, Asian battery makers, and more particularly, Chinese ones, almost have a complete mastery of the value chain except mining of some raw materials. Consequently, Europe and the United States have to tackle one key issue: the lack of mass production along the battery value chain, operated by local champions, which could jeopardize the sovereignty of their respective automotive industries. Europe and the United States have no other choice than using the same strategies already used by Chinese battery makers and trying to (re) localize, as much as possible, the complete value chain including recycling and reuse. However, it is much easier to say than to achieve. To evidence this statement, the 60kWh battery of a Megane e-tech has 288 cells and producing a car per minute means producing five cells per second! One must not underestimate the level of CAPEX and of fine-tuned manufacturing competencies required to do so, especially given the deadlines which have been set.

⁵³ European New Car Assessment Program, independent program to assess and compare safety ratings of cars. Achieving Five-star Euro NCAP requires a very good overall design capacity

⁵⁴ Prices in France as of February 1, 2023 before application of subsidies

⁵⁵ <https://www.defense.gov/News/Releases/Release/Article/2989973/> Defense Production Act Title III Presidential Determination for Critical Materials in Large-Capacity Batteries

Lastly, the criteria set in China for obtaining subsidies and NEV credit for a given model encompass the battery performance and have contributed to the current supremacy of the Chinese NEV industry. And again, we don't observe (yet) any regulation to include these criteria in European or American regulations.

Therefore, we already observe that both HV battery and vehicle Chinese regulations already have a strong impact of the competitiveness of the European and American automotive industries which are forced to catch up.

Finally, in this race against time, and putting apart the uncertain geopolitical context, China, Europe and the United States have an Achilles heel.

For China, how long will it be possible to support this "whatever it takes" policy that leads to production overcapacity, the elimination of many new entrants to the market and the associated huge sunk costs? Will Chinese battery makers have the capacity to lead, in such a dominant way, the production of the (potentially) ground breaking new technology, i.e., solid state?

For Europe and the United States, which, for the first time, are challengers to the Chinese NEV industry, aren't their reactions too late and/or too small-scale?

For Europe, in the absence of a supra-national program comparable to the Chinese national program, it is the technical, industrial, and economic capacities and/or the political agenda of each member state that, as much as the political will of the European Commission, influence the dynamics of the transition. Moreover, the European Commission's commitment to fair competition limits the actions that can be taken against competitors who do not (always) abide by the same rules.

For the United States, it is the political uncertainty at the federal level that could produce very serious damage to the industry if a political change occurs in early 2025 and triggers a further setback on the transition to electrification. However, the Bipartisan Infrastructure law and IRA Acts have funding allocated through 2032 that an opposing administration might have a hard time cutting, especially for job-creating projects.

5. Conclusion

The very stringent regulations in favor of carbon-free mobility enacted in China, Europe and the United States force the global automotive industry to a very deep transformation from ICEVs to plug-in vehicles. We are only at the beginning, since, to be in line with the Paris

agreements, EVs will have to represent between 50% and 60% of production in 2030, which could require increasing batteries production capacity up to 5,500 GWH⁵⁶.

This is a race against time for the industry, inherently uncertain and even more so, given the very difficult global context (Covid-19 crisis, semiconductor supply constraints, increasing geopolitical risks). Putting apart, for a while, this uncertain context and elaborating on recent results (Alochet et al., 2023), we hypothesize that automakers have the knowledge and capacity to produce this amount of BEVs. Therefore, the ability to scale up mass production of batteries in such a short period of time, while improving product and manufacturing performances, developing new technology (i.e., solid state), and addressing potential raw material scarcity issues, is the real bottleneck in the electrification race.

So far, China, thanks to the implementation of an administered Darwinism, is leading the game and taking advantage of a ten years lead over their Western competitors to seize the opportunity to overcome them and shape the future of the automotive global industry turned electric (Alochet & Midler, 2021).

With more than 75 percent of batteries currently produced in China, the United States and Europe, to avoid irreversible economic and sovereignty problems, must develop, at a very rapid pace, local champions having the capacity of mass-producing batteries and control the value chain. But the current dynamics of the Chinese industry as well as contracts or alliances already concluded by European and American automakers with Asian battery manufacturers for the coming years will weigh on the pace of development of local champions.

For the first time, in the long history of the automotive industry, the western industries are in position of challengers. They suffer the consequences of their lack of anticipation of regulations adapted to the systemic innovation required by the transition toward decarbonized mobility and of a very comprehensive, pragmatic and impactful set of Chinese regulations.

Consequently, the ability of European and American players to influence the global battery industry seems to be limited in the short term, while Asian players have this ability and use it extensively to expand globally. This forced march toward battery value chains localization could prefigure the subsequent creation of three production hubs serving their regional markets with Asian battery makers, mainly Chinese but also Japanese and Korean, taking the lead in the global market in the meantime. The question of whether the European and American

⁵⁶ <https://www.woodmac.com/press-releases/global-lithium-ion-battery-capacity-to-rise-five-fold-by-2030/>

automotive industries will be able to control their local HV battery production hubs remains open.

Finally, this case study shows that such a profound and systemic innovation is not produced by the sole meeting of industry and customers on a new value proposition: the positive or negative impacts of the regulations enacted or to come are major for the future of the automotive industry.

References

- ACC. (2023). *A Sustainable Supply Chain*. <https://www.acc-emotion.com/csr/sustainable-supply-chain>
- Akpinar, M. (2017). The exercise of power in inter-organisational relationships in response to changes in the institutional environment: Cases from the European automotive industry. *International Journal of Automotive Technology and Management*, 17(1), 51-71.
- Alochet, M., MacDuffie, J. P., & Midler, C. (2023). Mirroring in production? Early evidence from the scale-up of Battery Electric Vehicles (BEVs). *Industrial and Corporate Change*, 32(1), 61–111.
- Alochet, M., & Midler, C. (2019). Reorienting electric mobility research focus on industrialization issues. *International Journal of Automotive Technology and Management*, 19(3/4), 229–256.
- Alochet, M., & Midler, C. (2021). Une comparaison des politiques publiques chinoises et européennes sur le véhicule électrique. *Le Journal de l'Ecole de Paris*, 6(152), 16–23.
- Chen, Z., & He, H. (2021). *The second phase of China's new energy vehicle mandate policy for passenger cars*. ICCT. <https://theicct.org/publication/the-second-phase-of-chinas-new-energy-vehicle-mandate-policy-for-passenger-cars/>
- EBA 250. (2021, December). *Significant upstream developments in the European battery value chain*. <https://www.eba250.com/significant-upstream-developments-in-the-european-battery-value-chain/>
- ECA. (2019). *The EU's response to the "dieselgate" scandal* (No. 01/2019). European Court of Auditors. <https://www.eca.europa.eu/en/Pages/DocItem.aspx?did={F720CED7-25F5-4010-AC44-1BF91EF346DE}>

- European Commission. (2022a, October). *Zero emission vehicles: First 'Fit for 55' deal will end the sale of new CO2 emitting cars in Europe by 2035*. Zero emission vehicles: first 'Fit for 55' deal will end the sale of new CO2 emitting cars in Europe by 2035
- European Commission. (2022b, November 10). *Commission proposes new Euro 7 standards to reduce pollutant emissions from vehicles and improve air quality*.
https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495
- Fligstein, N. (1996). Markets as politics: A political-cultural approach to market institutions. *American Sociological Review*, 61(4), 656–673.
- General Motors. (2018, October 26). *General Motors Calls for National Zero Emissions Vehicle (NZEV) Program*. Media.Gm.Com.
<https://media.gm.com/content/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2018/oct/1026-emissions.html>
- IEA. (2020). *Commissioned EV and energy storage lithium-ion battery cell production capacity by region, and associated annual investment, 2010–2022*. International Energy Agency.
<https://www.iea.org/data-and-statistics/charts/commissioned-ev-and-energy-storage-lithium-ion-battery-cell-production-capacity-by-region-and-associated-annual-investment-2010-2022>
- IEA. (2021). *Global EV outlook 2021* [Technology report]. International Energy Agency.
<https://www.iea.org/reports/global-ev-outlook-2021>
- IEA. (2022). *Global Supply Chains of EV Batteries* [Technical report]. International Energy Agency. <https://www.iea.org/reports/global-supply-chains-of-ev-batteries>
- Jetin-Duceux, A. (2022). *EU and China EV Battery Policies: Different Approaches, Same Outcome?* Department of Land Economy, University of Cambridge.
- Klebaner, S., & Ramirez Perez, S. (2022). The European Automotive Industry: A Strategic Sector in Search of a New Industrial Policy. In J.-C. Defraigne, J. Wouters, E. Traversa,

- & D. Zurstrassen (Eds.), *EU Industrial Policy in the Multipolar Economy* (pp. 304–331). Edward Elgar Publishing.
- Lindblom, C. (2001). *The Market System: What It Is, How It Works, and What to Make of It*. Yale University Press.
- Liu, Y., & Kokko, A. (2013). Who does what in China’s new energy vehicle industry? *Energy Policy*, 57, 21–29. <https://doi.org/10.1016/j.enpol.2012.05.046>
- Midler, C., Alochet, M., & de Charentenay, C. (2023). *The Innovation Odyssey, lessons from an impossible project*. Taylor and Francis.
- Muniz, S. T. G., Belzowski, B. M., & Zhu, J. (2019). The trajectory of China’s new energy vehicles policy. *International Journal of Automotive Technology and Management*, 19(3–4), 257–280.
- Nelson, R. R. (1994). The co-evolution of technology, industrial structure, and supporting institutions. *Industrial and Corporate Change*, 3(1), 47–63.
- Northvolt. (2021, December). *Northvolt assembles first lithium-ion battery cell at Swedish gigafactory*. <https://northvolt.com/articles/first-cell/>
- Northvolt. (2023). *Make oil history*. <https://northvolt.com/>
- Pardi, T. (2021). Prospects and contradictions of the electrification of the European automotive industry: The role of European Union policy. *International Journal of Automotive Technology and Management*, 21(3), 162–179.
- Song, N., & Suzuki, H. (2019, December). *Will Chinese EV start-ups reshape the automotive industry?* | Arthur D. Little. <https://www.adlittle.com/en/insights/viewpoints/will-chinese-ev-start-ups-reshape-automotive-industry>
- The White House. (2021, August). *FACT SHEET: President Biden Announces Steps to Drive American Leadership Forward on Clean Cars and Trucks*. <https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet->

president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/

The White House. (2022, October). *FACT SHEET: Biden-Harris Administration Driving U.S. Battery Manufacturing and Good-Paying Jobs*. <https://www.whitehouse.gov/briefing-room/statements-releases/2022/10/19/fact-sheet-biden-harris-administration-driving-u-s-battery-manufacturing-and-good-paying-jobs/>

US EPA. (2022, March). *EPA Restores California's Authority to Enforce Greenhouse Gas Emission Standards for Cars and Light Trucks*. <https://www.epa.gov/newsreleases/epa-restores-californias-authority-enforce-greenhouse-gas-emission-standards-cars-and>

Verkor. (2022, March). *EU Battery Regulation: The top 4 European battery players take a common position on an ambitious framework for low-carbon batteries*. <https://verkor.com/en/eu-battery-regulation-the-top-4-european-battery-players-take-a-common-position-on-an-ambitious-framework-for-low-carbon-batteries/>

Wang, N., Tang, L., & Pan, H. (2019). A global comparison and assessment of incentive policy on electric vehicle promotion. *Sustainable Cities and Society*, 44, 597–603.

Wang, X., Zhao, W., & Ruet, J. (2022). Specialised vertical integration: The value-chain strategy of EV lithium-ion battery firms in China. *International Journal of Automotive Technology and Management*, 22(2), 178–201.

Weible, C. M., & Sabatier, P. A. (2018). *Theories of the policy process*. Routledge.

Weiss, M., Bonnel, P., Hummel, R., Manfredi, U., Colombo, R., Lanappe, G., Le Lijour, P., & Sculati, M. (2011). *Analyzing on-road Emissions of Light-duty Vehicles with Portable Emission Measurement Systems (PEMS)* (Technical Report EUR 24697 EN). European Commission. <https://publications.jrc.ec.europa.eu/repository/handle/JRC62639>

Wesseling, J. H. (2016). Explaining variance in national electric vehicle policies. *Environmental Innovation and Societal Transitions*, 21, 28–38.

Yuan, X., Liu, X., & Zuo, J. (2015). The development of new energy vehicles for a sustainable future: A review. *Renewable and Sustainable Energy Reviews*, 42, 298–305.
<https://doi.org/10.1016/j.rser.2014.10.016>

Appendix 1: Summary of sources of regulatory information

Region of the world	Main regulatory organizations	Field of competences (in general)	Field of competences (in the context of our study)	Accessed (front) websites
China	National Development and Reform Commission of the People's Republic of China (NDRC, created in 1952)	National economic development	Development of HV battery and NEV industries	There are no sites giving access to regulations promulgated by NDRC or by each Ministry The regulations we cite are extracted from a list obtained after a document search, by a Chinese scholar, of keywords such as “new energy vehicle,” “pure electric passenger car,” and “power battery.” The search was conducted on the websites of MIIT, NDRC, MOST, and MOF and crosschecked with a Google search for “China NEV policy + [year]”.
	the Ministry of Industry and Information (MIIT, created in 2008)	To determine China’s industrial planning, policies and standards	Regulations related to electrification	
	The Ministry of Science and Technology (MOST, created in 1998)	To coordinate national science and technology activities	Research programs related to electrification	
	The Ministry of Finance (MOF, created in 1949)	To administer macroeconomic policies... and handle fiscal policy, [and] economic regulations... for the state	Subsidies regulations	
Europe	DG GROW (Growth)	Internal Market, Industry, Entrepreneurship and SMEs	Responsible for the development of European Raw Materials Alliance and European Battery Alliance (EBA) Responsible of reduction of pollutants emissions	For batteries industry: https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances_en For reduction of vehicles emissions: https://single-market-economy.ec.europa.eu/sectors/automotive-industry/environmental-protection/emissions-automotive-sector_en For batteries regulations: https://environment.ec.europa.eu/topics/waste-and-recycling/batteries-and-accumulators_en
	DG CLIMA (Climate Action)	This department leads the European Commission's efforts to fight climate change at EU and international level	Responsible of reduction of GHG emissions	
	DG ENV (Environment)	This Commission department is responsible for EU policy on the environment. It proposes and implements policies that ensure a high level of environmental protection and preserve the quality of life of EU citizens.	Responsible of regulations about waste and recycling including batteries (all types)	
United states	California Air Resources Board (CARB)	CARB is the primary state agency responsible for actions to protect public health from the harmful effects of air pollution	Promulgation of regulations aiming at reducing pollutants and GHG emissions from ICEVs as well as those forcing automakers to produce more and more ZEVs over time	https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/about
	United States Environmental Agency (EPA)	The U.S. Environmental Protection Agency (EPA) is responsible for the protection of human health and the environment.	GHG emissions regulations Under the Resource Conservation and Recovery Act (RCRA) Regulations, EPA enacts regulations about batteries	https://www.epa.gov/regulatory-information-topic/regulatory-and-guidance-information-topic-air#transport

	National Highway Traffic Safety Administration (NHTSA)	The National Highway Traffic Safety Administration is responsible for keeping people safe on America's roadways	NHTSA's Corporate Average Fuel Economy (CAFE) standards regulate how far our vehicles must travel on a gallon of fuel	https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy
	Department of Energy	The mission of the Energy Department is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions	Battery (for electric vehicles) incentives and policies	https://www.energy.gov/eere/vehicles/battery-policies-and-incentives-search#/?jurisdiction=US

Appendix 2: summary of Battery policies and incentives enacted by the US department of Energy

Title	Type	Status	Content
Battery and EV Manufacturing tax credit	Incentive	amended 8/16/2022	Qualified advanced energy projects are eligible for a 30% tax credit for project investments to reequip, expand, or establish certain energy manufacturing that reequip, expand, or establish a manufacturing or industrial facility for the production or recycling of energy storage systems and components, electric or fuel cell vehicles and components, grid modernization equipment and components, and more.
Battery requirements for EV and FCEV tax credits	Incentive	enacted 8/16/2022	Beginning January 1, 2023, the Clean Vehicle Credit provisions establish criteria for a vehicle to be considered eligible that involve sourcing requirements for critical mineral extraction, processing, and recycling and battery component manufacturing and assembly. Vehicles that meet critical mineral requirements are eligible for \$3,750 tax credit, and vehicles that meet battery component requirements are eligible for a \$3,750 tax credit. Vehicles meeting both the critical mineral and the battery component requirements are eligible for a total tax credit of up to \$7,500.
EV Battery research grant	Incentive	enacted 5/3/2022	The Electric Vehicles for American Low-Carbon Living (EVs4ALL) program provides grants for research and development projects that seek to reduce the cost of EV batteries, improve EV charging times, increase battery efficiency in cold weather, and improve EV battery range and resilience.
Clean Energy supply chain study	Policy	enacted 2/24/2022	The U.S. Department of Energy (DOE) must conduct a study on clean energy manufacturing supply chains, including high-capacity batteries, electric vehicle batteries, rare earth magnets, and semiconductors. The study must identify risks in the supply chain and propose policy recommendations
Battery recycling and 2nd life application program	Incentive	enacted 2/11/2022	The U.S. Department of Energy (DOE) will issue grants for research, development, and demonstration of electric vehicle (EV) battery recycling and second use application projects in the United States. Eligible activities will include second-life applications for EV batteries, and technologies and processes for final recycling and disposal of EV batteries.
Advanced Vehicle Technology Manufacturing program loan program	Incentive	amended 11/15/2021	Through the U.S. Department of Energy's (DOE) ATVM Loan Program, manufacturers may be eligible for direct loans of up to 30% of the cost of reequipping, expanding, or establishing manufacturing facilities in the United States used to produce qualified advanced technology vehicles (ATVs) or ATV components, including associated hardware and software. Qualified ATVs are light-, medium-, and heavy-duty or ultra-efficient vehicles that meet specified federal emission standards and fuel economy requirements.
Annual critical materials outlook	Policy	enacted 11/15/2021	By May 2022, the U.S. Energy Information Administration (EIA), in coordination with the U.S. Geological Survey, must develop a plan for modeling and forecasting of demand for energy technologies, including for energy production, transmission, or storage purposes, that use critical minerals. The plan must produce forecasts of energy technology demand over 1-year, 5-year, and 10-year periods. EIA and the U.S. Department of the Interior may require additional parameters to develop the Annual Critical Minerals Outlook
Demonstration of EV battery second life application for grid services	Incentive	enacted 11/15/2021	The U.S. Department of Energy (DOE) must enter into an agreement to carry out a project to demonstrate second life applications of EV batteries as aggregated energy storage installations to provide services to the electric grid.
Electric drive battery recycling and second life applications	Incentive	enacted 11/15/2021	The U.S. Department of Energy (DOE) must carry out a research, development, and demonstration program of second-life applications for used electric drive vehicle batteries and technologies and processes for final recycling and disposal.

EV studies	Policy	enacted 11/15/2021	The U.S. Department of Energy (DOE) must conduct a study on the cradle-to-grave environmental impact of EVs, including batteries. DOE, in coordination with the U.S. State Department and the U.S. Department of Commerce, must also study the impact of forced labor in China on the EV supply chain. Both studies must submit reports to Congress by March 15, 2022.
EV working group	Policy	enacted 11/15/2021	The Secretaries of Transportation and Energy must jointly establish an EV working group to make recommendations regarding the development, adoption, and integration of light-, medium-, and heavy-duty EVs into the transportation and energy system of the United States. The working group will comprise of 25 members from federal agencies, the automotive industry, EV battery manufacturers, the energy industry, state and local governments, labor organizations, and the property development industry.
Energy workforce advisory group	Policy	enacted 11/15/2021	The U.S. Department of Energy (DOE) will establish a 21st Century Energy Workforce Advisory Board to develop a strategy to support and develop a skilled energy workforce
LI-Bridge	Incentive	enacted 10/27/2021	Li-Bridge, led by the U.S. Department of Energy's (DOE) Argonne National Laboratory (ANL), is a public-private alliance committed to accelerating the development of a robust and secure domestic supply chain for lithium-based batteries. Li-Bridge brings key stakeholders together to improve the lithium battery supply chain.
Support for US innovation for clean cars and trucks	Policy	enacted 8/5/2021	Executive Order 14037, issued in August 2021, sets a goal that 50% of all new passenger cars and light trucks sold in 2030 be zero-emission vehicles, including all-electric, plug-in hybrid electric, or fuel cell electric vehicles.
US Supply chain review	Policy	enacted 2/24/2021	Executive Order 14017, issued in February 2021, directs federal agencies to assess vulnerabilities in, and strengthen the resilience of, critical supply chains. Federal agencies, in consultation with outside stakeholders, including industry, academia, non-governmental organizations, communities, labor unions, and governments, must complete a review of supply chain risks within 100 days of February 24, 2021.
Energy storage system Research, development and deployment program	Incentive	enacted 12/28/2020	The U.S. Department of Energy (DOE) must establish an Energy Storage System Research, Development, and Deployment Program. The initial program focus is to further the research, development, and deployment of short- and long-duration large-scale energy storage systems, including, but not limited to, distributed energy storage technologies and transportation energy storage technologies
Advanced energy research project grants	Incentive	amended 12/27/2020	The Advanced Research Projects Agency – Energy (ARPA-E) was established within the U.S. Department of Energy with the mission to fund transformational domestic energy projects. ARPA-E focuses on various early-stage concepts in multiple program areas including, but not limited to, battery technologies, vehicle technologies, and energy storage.
Additional funding opportunities	Incentive	enacted 12/10/2020	Additional funding opportunities that are not offered through existing, permanent funding mechanisms, but that are relevant to the scope of the Battery Policies and Incentives Database may arise.
Vehicle Technology Office	Incentive	enacted 12/10/2020	The U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) supports research, development, and deployment of efficient and sustainable transportation technologies, including advanced batteries and lightweight materials.
Federal Consortium for Advanced Batteries (FCAB)	Policy	enacted 9/10/2020	Through FCAB, federal agencies are encouraged to coordinate advanced battery efforts and develop a domestic battery supply chain.

Appendix 3: (Some) JVs and contracts set by American automakers with battery makers for EVs production in North America

Automaker	Battery Maker	Production Location	Source
Ford	SK Innovation	Tennessee, Kentucky	https://skinnonews.com/global/archives/7245
GM	LG ES	Michigan, Ohio, Tennessee	https://www.gm.com/stories/manufacturing-ultium-evs-trucks
Lucid Air	LG ES	LGES own plant in Michigan	https://www.lucidmotors.com/media-room/lucid-motors-announces-partnership-lg-chem-secures-battery-cells-long-term-volume-production
	Panasonic Energy	Japan then Panasonic future plant in Kansas	https://www.lucidmotors.com/media-room/panasonic-agreement-supply-lithium-ion-batteries
Rivian	Samsung SDI	Asia	https://www.electrive.com/2021/04/13/rivian-to-source-batteries-from-samsung-sdi/
Stellantis	LG ES	Canada	https://www.stellantis.com/en/news/press-releases/2022/march/stellantis-and-lg-energy-solution-to-invest-over-5-billion-cad-in-joint-venture-for-first-large-scale-lithium-ion-battery-production-plant-in-canada
	Samsung SDI	Indiana	https://www.stellantis.com/en/search?q=stellantis+samsung+battery+plant
Tesla	Panasonic Energy	Nevada plus future plant in Kansas	https://www.tesla.com/giga-nevada

Appendix 4: (Some) Announcements made by American automakers to develop battery upstream value chain in North America

Automaker	Company	Nature of supply	Location of production	Source
GM	Lithium Americas Corp.	Lithium	Mining in Nevada	https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2023/jan/0131-lithium.html
GM	Microvast Holdings, Inc.	Battery separator	New plant to be built in USA	https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2022/nov/1102-microvast.html
GM	Vale Canada Limited	Nickel sulfate	Production plant in Quebec	https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2022/nov/1117-vale.html
Ford	Ioneer Ltd's	Lithium	Mining in Nevada	https://www.reuters.com/business/autos-transportation/ford-buy-lithium-ioneer-american-ev-battery-plant-2022-07-21/
Ford	Compass Minerals	Lithium	Solar evaporation facility in Utah	https://www.compassminerals.com/info/news/compass-minerals-and-ford-motor-company-sign-non-binding-agreement-for-the-supply-of-battery-grade-lithium/
Ford	SK On and EcoPro BM	Cathode	New plant to be built in Quebec	https://www.bloomberg.com/news/articles/2022-11-04/ford-in-talks-with-korean-firms-to-build-cathode-plant-in-quebec
Stellantis	Element25	Manganese sulphate monohydrate	New plant to be built in USA	https://www.stellantis.com/en/news/press-releases/2023/january/stellantis-signs-binding-agreement-with-element-25-limited-for-manganese-sulphate-supply-for-electric-vehicle-batteries
Stellantis	Controlled Thermal Resources Ltd.	Lithium	Process lithium from geothermal brines in California	https://www.stellantis.com/en/news/press-releases/2022/june/stellantis-secures-low-emissions-lithium-supply-for-north-american-electric-vehicle-production-from-controlled-thermal-resources

Appendix 5: (Some) JVs and contracts set by European automakers with battery makers for EVs production in Europe

Automaker	Battery Maker	Production Location	Source
BMW	Northvolt (Sweden)	Skellefteå (Sweden)	https://www.bmwgroup.com/en/company/news.html#ace-968725116
	CATL (China)	Erfurt (Germany)	https://www.bmwgroup.com/en/company/news.html#ace-1823904677
	Samsung SDI (South Korea)	Göd (Hungary)	
Daimler	CATL (China)	Debrecen (Hungary)	https://group.mercedes-benz.com/innovation/digitalisation/industry-4-0/article-2.html
	ACC (France)	Kaiserslautern (Germany)	https://group.mercedes-benz.com/company/news/mercedes-benz-update-battery-strategy.html
Renault Group	Verkor (France)	Dunkerque (France)	https://media.renaultgroup.com/renault-group-places-france-at-the-heart-of-its-industrial-strategy-for-ev-batteries/?lang=eng
	Envision Group (China)	Douai (France)	
Stellantis	ACC (France)	Termoli (Italy)	https://www.stellantis.com/en/news/press-releases/2022/march/stellantis-affirms-commitment-to-italy-with-automotive-cells-company-s-acc-planned-battery-plant-investment
		Douvrin (France)	https://www.acc-emotion.com/stories/acc-announces-opening-3rd-gigafactory-termoli-italy
		Kaiserslautern (Germany)	
PowerCo ⁵⁷	Northvolt (Sweden)	Skellefteå (Sweden)	https://northvolt.com/articles/northvoltt-supply/
	Gotion High-Tech (China)	Salzgitter (Germany)	https://www.volkswagen-newsroom.com/en/press-releases/volkswagen-group-and-gotion-high-tech-team-up-to-industrialize-battery-cell-production-in-germany-7316

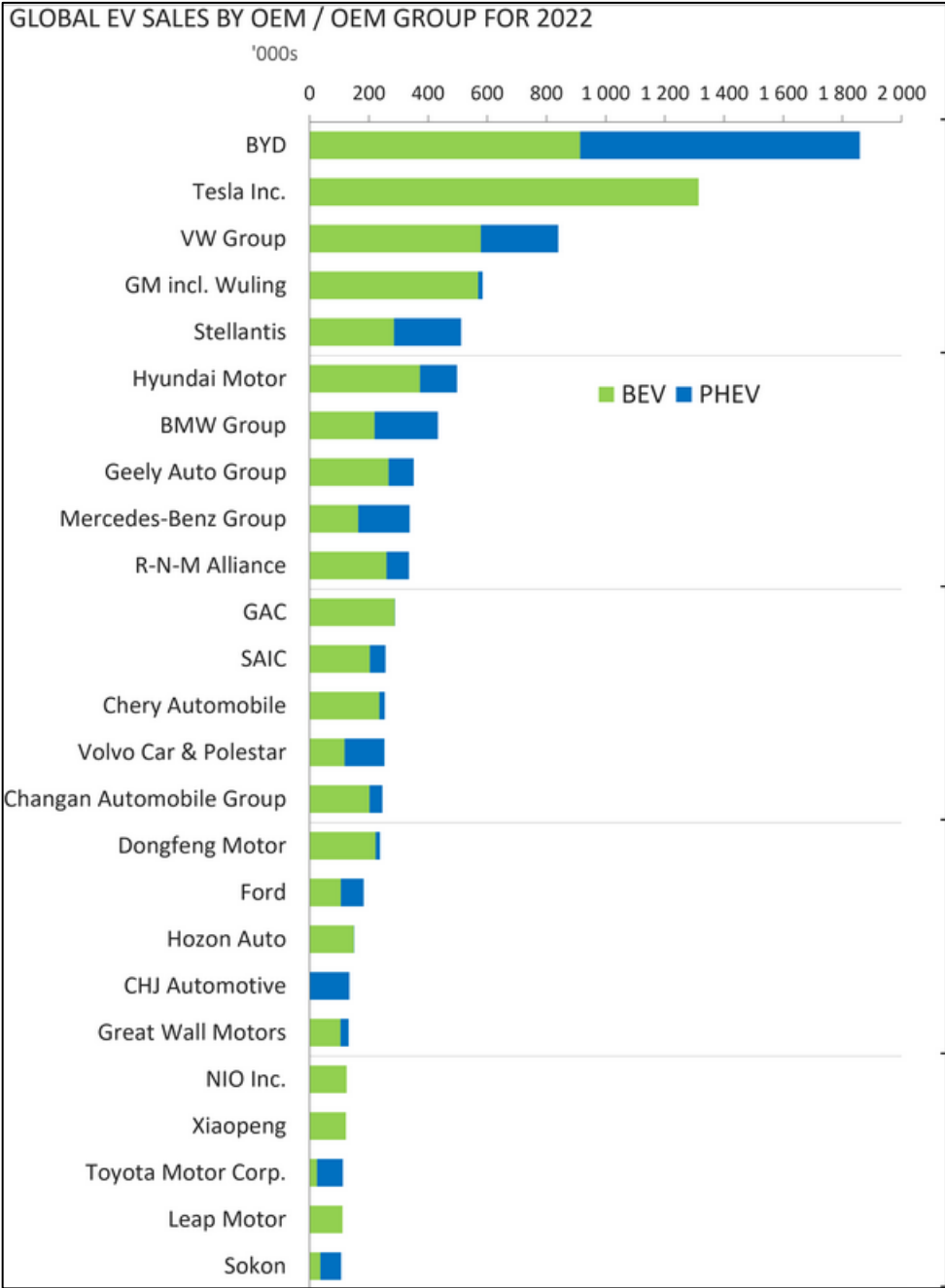
⁵⁷ PowerCo is the European company established by VW to consolidate activities along the complete value chain for batteries (<https://www.powerco.de/#>)

Appendix 6: (Some) Announcements made by European automakers to develop battery upstream value chain in Europe

Automaker	Company	Nature of supply	Location of production	Source
BMW ⁵⁸	Managem	Cobalt	Mining in Morocco (Remaining 80% in Australia)	https://www.press.bmwgroup.com/france/article/detail/T0310910FR/approvisionnement-en-mati%C3%A8res-premi%C3%A8res-pour-les-cellules-de-batterie:-bmw-group-s-approvisionne-en-cobalt-durable-au-maroc-pour-une-valeur-d-environ-100-millions-d-euros?language=fr
Renault Group	Terrafame	Nickel sulphate	Bioleaching-based production process in Finland	https://media.renaultgroup.com/renault-group-to-partner-with-terrafame-for-sustainable-nickel-supply/?lang=eng
	Vulcan Energy	Lithium	Germany	https://media.renaultgroup.com/renault-group-signe-un-accord-avec-vulcan-energy-pour-un-approvisionnement-decarbone-et-europeen-en-lithium/?lang=fra
Stellantis	Terrafame	Nickel sulphate	Bioleaching-based production process in Finland	https://www.stellantis.com/en/news/press-releases/2023/january/stellantis-and-terrafame-agree-on-low-carbon-nickel-sulphate-supply-for-electric-vehicle-batteries
	Vulcan Energy	Lithium	Germany	https://www.stellantis.com/en/news/press-releases/2021/november/stellantis-signs-lithium-supply-agreement-with-vulcan-energy
PowerCo	Umicore	Cathodes (and components)	Belgium	https://www.volkswagenag.com/en/news/2022/09/powerco-and-umicore-establish-joint-venture-for-european-battery.html#
	Vulcan Energy	Lithium	Germany	https://www.volkswagenag.com/en/news/2021/12/volkswagen-enters-into-strategic-partnerships-for-the-industrial.html

⁵⁸ This is not a sourcing from Europe but demonstrates an effort to reduce the CO2 footprint of the battery value chain

Appendix 7: Ranking of OEMs, OEM Groups per decreasing sales of EVs in thousands of vehicles –2022



Source: <https://www.ev-volumes.com/> accessed on February 6, 2023

Appendix 8: List of policies promulgated by the NDRC, MIIT, MOST and MOF dealing with subsidies related to product (vehicle, battery system) performance

Date	Institution(s)	Policy title	Web sources
2010, May 31	MOF, MOST, MIIT, NDRC	Notice on launching the pilot program of subsidies for private purchase of new energy vehicles	https://www.ndrc.gov.cn/xxgk/zcfb/qt/201006/t20100603_967777.html
2013, September 13	MOF, MOST, MIIT, NDRC	Notice on continuing to promote the application and application of new energy vehicles	http://www.gov.cn/zwgk/2013-09/17/content_2490108.htm
2014, August 1	MOF, State Taxation Administration, MIIT	Announcement on exemption of new energy vehicle purchase tax - Announcement No. 53 of 2014	http://www.chinatax.gov.cn/n810341/n810755/c1150779/content.html
2015, April 22	MOF, MIIT, MOST, NDRC	Notice of the Four Ministries on the financial support policy for the promotion and application of new energy vehicles in 2016-2020	http://www.gov.cn/xinwen/2015-04/29/content_2855040.htm
2016, December 29	MOF, MIIT, MOST, NDRC	Notice on Adjusting the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles	http://www.gov.cn/xinwen/2016-12/30/content_5154971.htm#allContent
2017, December 26	MOF, State Taxation Administration, MIIT, MOST	Announcement of the four departments (MOF, Administration of Taxation, MIIT, MOST) on the exemption of new energy vehicle purchase tax	http://www.gov.cn/xinwen/2017-12/28/content_5251086.htm
2018, February 12	MOF, MIIT, MOST, NDRC	Notice of the Four Ministries (MOF, MIIT, MOST, NDRC) on Adjusting and Perfecting the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles	https://www.miit.gov.cn/zwgk/zcwj/wjfb/zbgj/art/2020/art_2d4ca29e16bc4fe08c5637641948cc38.html
2019, March 26	MOF, MIIT, MOST, NDRC	New energy vehicle promotion subsidy program and product technical requirements	http://www.gov.cn/xinwen/2019-03/27/content_5377123.htm
2020, April 23	MOF, MIIT, MOST, NDRC	Notice on improving the financial subsidy policy for the promotion and application of new energy vehicles	http://www.gov.cn/zhengce/zhengceku/2020-04/23/content_5505502.htm
2020, December 31	MOF, MIIT, MOST, NDRC	Notice on Further Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles	http://www.gov.cn/zhengce/zhengceku/2020-12/31/content_5575906.htm
2021, January 1	MIIT	Parallel Management Regulation for Corporate Average Fuel Consumption and New Energy Vehicle Credits for Passenger Cars	https://www.miit.gov.cn/zwgk/zcwj/flfg/art/2020/art_2337a6d7ca894c5c8e8483cf9400ecdd.html