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THE CAR INDUSTRY AND CLIMATE CHANGE: A HISTORICAL REVIEW

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The Car Industry and Climate Change: A Historical Review[1]

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Abstract: In the second half of the twentieth century, the car industry became a lightning rod for debates about human contributions to climate change. Widespread motorisation galvanised the green movements of the 1960s and 1970s, regulators increasingly demanded the use of pollution and climate mitigation technologies, and carmakers responded to this changing consumer and regulatory environment by gradually observing stricter emissions standards and innovating away from combustible engines at the turn of the millennium. This paper traces the arc of the relationship between car manufacturing and climate change through a business historical lens, from the development of internal combustion engines and their alternatives to the political economy of an energy transition and the decision to prioritise electric vehicles. Our analysis aims to lay a foundation for further research on industry and climate change.

Keywords: environmental history, business history, automakers, regulation, climate governance

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Introduction

The car industry has been one of the most environmentally consequential industries since its emergence in the early twentieth century, and its historical dependence on fossil fuels underscores its cumulative and negative impact on greenhouse gas emissions and global warming.[4] Climate change emerged widely on political agendas only in the late 1980s,[5] and policies aimed at climate change mitigation were introduced in the 1990s, especially following the signing of the Kyoto Protocol in late 1997.[6] Despite efforts to reduce the climate impact of the road transportation sector, car emissions have been growing faster than most sectors since the 1970s, trailing only the growth in emissions from industrial processes, electricity, and heating.[7] In 2019, road transportation was responsible for 12.6% of global greenhouse gas emissions and roughly 17% of all carbon dioxide (CO2) emissions, on par with emissions from the manufacturing and construction sectors.[8]

Over the last decade, governments around the world have applied mounting pressure to decarbonise the car industry by eliminating the carbon dioxide emissions it produces. In 2023 for example, the European Union (EU) passed a regulation to limit new car registrations to vehicles emitting zero CO2 emissions.[9] With government support and

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[4] Creutzig et al., "Transport."

[5] Bodansky, "The History."

[6] UNFCC, "Kyoto Protocol."

[7] Creutzig et al., "Transport"; Lamb et al., "Countries."

[8] Climate Watch, "World Greenhouse Gas Emissions."

[9] EU, Regulation 2023/851. This regulation is set to take effect in 2035. Importantly, a backdoor for vehicles running on e-fuels was left open. See below.

pressure, the car industry has seemingly begun to replace the fossil fuel powered internal combustion engine (ICE) with engines powered by electricity, which promise no pollutant or greenhouse gas emissions.[10] The car industry has thus become the focus of green transition policy, largely because of its forward and backward linkages to other industries and because of the enormous size of the consumer car market; as a result, the car industry has become a high-profile case for wider green transition. It is important to recognize, however – and is potentially instructive for other areas of the economy – that the industry's shift toward EVs is the joint product of both policy choices and consumer demand. Pressured by European legislation, large manufacturer groups such as Volkswagen and Stellantis have set targets to sell only EVs in Europe by 2030-35, and specialist producers, such as Volvo Cars, Mitsubishi, and Rolls Royce, have goals to go fully electric in the same period, whereas Tesla and BYD, responding to consumer demand and political incentives, are already selling only EVs.[11] By contrast, Toyota North America's CEO Ted Ogawa expressed scepticism about long term consumer demand for EVs in the US, given both the insufficient public and private investment in the charging infrastructure required for a full electric transition and persistent climate scepticism among American drivers, and said he would rather "buy [emissions] credits" than "waste" money on further investment in EV production.[12] Champion of the "hybrid" car, Toyota is banking instead that a flexible mix of petrol and power will be a better business strategy for the

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[10] IEA, *Global EV Outlook.*

[11] Ibid., p. 90-91; Duffy, "Every Car Brand."

[12] Mossalgue, "Toyota."

US market. Toyota's hybrid approach has proven highly lucrative as US car sales and registrations of EVs have slowed in recent years.

As the following sections show, governments have viewed electrification in the car industry, on the one hand, as a means of addressing the issue of climate change and, on the other, as a means of achieving a competitive edge in intensifying geoeconomic competition. Such contemporary developments have highlighted business strategies for responding to the global governance of the climate and environmental policy regulation, both at the national and international levels.[13] They also demand careful consideration of the relational history of cars and climate change.

This paper takes a business historical approach to cars and climate change by examining how the car industry and carmakers have contributed to greenhouse gas emissions and responded to increasing climate change mitigation.[14] It is motivated by the relative lack of attention historians have paid to the developments of recent decades, and it highlights the importance of history for understanding the ways business and governments/governance institutions might approach the future. We focus on passenger cars specifically, rather than automotives broadly, since they represent the highest volume of vehicles producing emissions, although we also briefly discuss light-trucks since their role in private transportation has increased dramatically since the 1990s.

[13] On the historical relationship of business and global governance, see: Ballor and Pitteloud, "Capitalism and Global Governance."

[14] On business and environmental activism, see ongoing work by Sabine Pitteloud.

Our paper is in conversation with several literatures. Case studies on carmakers have long been the backbone of classical business history scholarship.[15] Recently, historians of science and technology have traced the development of scientific research on anthropogenic climate change and uncovered the ways some actors sewed public doubt about scientific findings and traced the early effects of climate change on developing countries.[16] There is also a growing body of scholarship on the history of business and environmental regulation, not only focused on the car industry.[17] But, as Ann-Kristin Bergquist noted, little historical scholarship has directly studied the car industry and the environment together: “[a] painful gap exists in the historical literature, the content of which could give a sense of the historically shaped inertias and difficulties in transforming this industry.”[18] This paper aims to fill that gap by tracing the evolution of the car industry, its negative effects on the environment and climate, national and international efforts to regulate vehicle emissions, and the industry’s shift toward new technologies as part of a wider energy transition. Such an approach underscores the importance of analysing industry perspectives and strategies in the process of green transition.

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[15] Chandler, *Strategy and Structure,* idem, *Giant enterprise*; Wilkins and Hill, *American Business Abroad*; Bardou et al., *The Automobile Revolution.*

[16] Oreskes and Conway, *Merchants of Doubt.* See also the ongoing PhD of Colleen Lanier Christensen at Harvard University.

[17] Bergquist and David, “Beyond Planetary Limits!”; Huf et al., “Planetary History”; Klebaner, *Normes environnementales européennes;* Bergquist and Näsman, “Safe before Green!”; Näsman, “The Political Economy”; Klebaner and Ramírez Pérez, “Managing Technical Changes”; Ballor, “Liberal Environmentalism.”

[18] Bergquist, "Renewing Business History.”

As a methodological note, studying contemporary and sensitive topics can be challenging for business historians, who typically rely on access to corporate archives for exploring the evolution of firm strategies, since most corporate archives restrict access to documents produced in the most recent 30 years, as is the case for the corporate archives of car companies like BMW and Volkswagen, for example. Additionally, corporate and institutional archives often keep sensitive material classified. Carmakers are generally cautious about offering corporate archive access to those studying environmental issues, especially after the "Dieselgate" scandal, which revealed that carmakers across the globe were using technology – so-called "defeat devices" – to circumvent regulatory emissions testing.[19] In part, these challenges of archive access explain the relative lack of historical scholarship on business and climate change, compared to other disciplinary inquiries. Some business historians have overcome the challenges of limited archival access through the use of alternative sources.[20] Oral history interviews and reports can provide crucial information otherwise obscured by archive rules and even serve as a "surveillance archive."[21] Interviews with former executives can illuminate aspects of business strategy not yet available in the written records of archived board minutes, and disclosure requirements oblige companies to divulge their investments in reports, which can likewise reveal much about business strategy.[22]

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[19] See, Hooftman et al., "A review."

[20] See: Bergquist and Näsman, "Safe before Green!."

[21] On the use of reports, see: Ballor et al., "Surveillance Archive."

[22] The Creating Emerging Markets Project at Harvard Business School has developed a model for using oral history interviews in business history scholarship: https://www.hbs.edu/creating-emerging-markets/Pages/default.aspx

This paper briefly reviews the history and historiography of the car industry and climate change from the formative decades of automobility in the late nineteenth century to the present (Section 1) and historicises business strategies to climate change (Section 2). We then take stock of contemporary developments including the car industry's shift toward electrification in the context of industrial policy and geopolitical competition (Section 3). This history is especially important for the present as Europe, the US, and China are all currently pushing for and competing over the future of the car industry. In what has been called a "second automotive revolution," the world's longstanding dependence on fossil fuels and the ICE is progressively giving way to electrification and the possibility of using renewable energy to power personal transportation.[23] Before concluding, we briefly assess private and public strategies to limit cars' CO2 emissions since the 1970s to draw conclusions on progress on climate mitigation up to the present.

I. A Brief Global History and Historiography of the Car Industry

Since the beginning of the twentieth century, the progressive global reliance on cars for personal transportation transformed the global energy landscape and created an ever-increasing demand for petroleum products. Thus, the "automotive age," beginning with the emergence of mass markets for cars in the US in the 1920s and in Western Europe in the 1960s, was thus also the "age of gasoline."[24] Historical research on energy transitions has emphasised that the addition of new sources of energy have not replaced

[23] Freyssenet, "Second Automobile Revolution". Freyssenet also includes autonomous driving capability in this revolution.

[24] Yergin, *The Prize*, chapter 11; Mira Wilkins, "Multinational Automobile Enterprises."

existing ones.[25] Hence, the automotive age did not mean that oil replaced coal, but rather that oil became an additional integral part of global energy systems.

In the late nineteenth century, European and American firms, entrepreneurs, and inventors competed against one another with a broad range of technologies to power their vehicles, from steam and electricity to biofuels and fossil fuels. Initially, the fossil fuel powered ICE won the battle of technologies, and, in part through Henry Ford's revolution in standardised mass-production beginning with the Model T in 1908, the ICE quickly became the dominant technology for passenger transportation.[26] The US rose quickly to become the world's leading car producing country. In 1908, it surpassed the previous leader, France, and topped the total production by all other producer countries, namely Britain, Germany, and Italy. While the US car industry was responsible for roughly 40% of the world's car production in 1903, it produced 61% of the world's cars by 1908 and 93% by 1913.[27]

As a consequence of increasing car drivership in the US in the early twentieth century, oil became a strategic resource of national interest, raising concerns and scientific debates in the 1920s about the potential consequences and probability of depleting known crude oil reserves.[28] Adding to such fears were the technical limitations of refining petrol from crude oil, soon alleviated by new discoveries of large crude fields in the US and the

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[25] Bergquist and Lindmark, "Energy Transitions."

[26] Flink, *The Automobile Age.* On global Fordism, see also: Link, *Forging Global Fordism.*

[27] Laux, *The European Automobile Industry*, 8.

[28] Yergin, *The Prize*, chapters 11 & 13.

advancement of refining technologies. Thermal cracking first used in 1913 doubled the yield of petrol that could be obtained from petroleum to 15%; catalytic cracking, introduced by the French chemist Eugene Houdry in the 1930s, subsequently increased the yield to 43%.[29] Together with the discovery of new crude sources, including in the Middle East, advancements in refining technologies significantly lowered the price of gasoline in the mid-twentieth century, while also igniting new geopolitical tensions.[30] Consumer culture around cars, whose creation has been promoted by the oil and car industry, deepened global dependence on oil to such an extent that cars and cheap access to oil and petrol became means of social and economic inclusion in developed countries.[31]

The US industry's global dominance in car production endured until the 1960s, when competition intensified, first from European and later from Japanese manufacturers. Consolidation was an integral part of the rise of the US car industry. While the US was home to several hundred carmakers in the early twentieth century, it quickly became dominated by the "Big Three" – General Motors, Ford, and Chrysler (now Stellantis) – which, together, claimed 85% of the US market by 1946.[32] In the US as elsewhere, postwar government policies facilitated the growth of the car industry and the expansion of car use, because domestic car production was seen by many governments as a proxy for modernisation as well as for economic and social development, reflected in national

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[29] Volti, *Cars and Culture,* 37-38.

[30] Vast oil reserves were discovered in the Arabian Peninsula in 1932, prompting Western powers, who were increasingly dependent on oil, to form alliances with the Kingdom of Saudi Arabia, Yergin, *The Prize,* 284-292. See also, Garavini, *The Rise and Fall.*

[31] Bini, "Back to the Future"; Giulio Mattioli, et al., "Car Dependence."

[32] Bardou et al., *The Automobile Revolution,* 176.

employment rates and living standards. Across the West, government investment was instrumental in creating the dense road networks that increased the use value of passenger car ownership, and government policies for wealth and income distribution facilitated the expansion of car use and contributed to a self-sustaining process of continued car industry growth in industrialised countries until 1974 and the wake of the first Oil Crisis.[33] After 1974, car industries continued to grow, albeit at a slower pace, accelerating again with the rise of the Chinese car industry in the 2000s.[34]

II. Business Strategies and the Political Economy of Technological Choice

i. Carmaker Strategies on Climate Change

In the mid-to late 1980s, climate change became a global political issue, according to law scholar Daniel Bodansky. Since the 1960s, scientists have been increasingly certain about the links between greenhouse gas emissions, notably CO2, and global warming. At the same time, there was also growing concern for global environmental issues in general, such as the discovery of the Antarctic ozone hole in 1985 that demonstrated anthropogenic effects on the atmosphere.[35] Bodansky shows that climate change, once dominated by non-governmental actors such as scientists, emerged as an intergovernmental issue in 1988, when a conference organised by the Canadian government in Toronto called for 20% reduction of CO2 emissions by 2005, the

[33] Freyssenet, "The Second Automobile Revolution," 443-454.

[34] Ibid.

[35] Bodansky, "The History," 26-27.

Intergovernmental Panel on Climate Change (IPCC) was created, and the UN General Assembly adopted a resolution calling climate change "a common concern for mankind."[36] Shortly after, 154 states signed the UN Framework Convention on Climate Change (UNFCCC) at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, which remains central to climate change governance even today.[37] To meet the 20% reduction target set by the Toronto Conference in 1988, the European Economic Community (EEC), US, and Japan considered the implementation of carbon taxes.[38]

Carmakers were quick to notice the potential business implications of climate policies. In 1989, the Global Climate Change Coalition (GCC), a notable actor organising US business opposition to climate change, was founded under the aegis of the US National Association of Manufacturers, and it counted Ford, Chrysler and General Motors, the Automobile Importers of America, and the Motor Vehicle Manufacturers Association among its members.[39] Scholarship on how the oil industry and oil companies created doubt about the science of climate change and how they organised climate opposition is quickly expanding.[40] But historians have yet to explore how the car industry and carmakers organised and positioned themselves in relation to the climate issue, including

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[36] Bodansky, "The History," 27-28.

[37] Bulkeley and Newell, *Governing Climate Change.*

[38] Franta "Weaponizing Economics."

[39] Brulle, "Advocating Inaction." For membership of GCC in 1989, see Climate Files, "1989 GCC Membership."

[40] See, e.g., Franta, "Weaponizing Economics"; Bonneuil et al., "Early Warnings."

about their role in the GCC vis-à-vis the oil, gas, and coal companies whose products were more directly affected by carbon taxes than cars.[41] However, other studies discussed below indicate a seeming difference between the US car industry and its European and Japanese counterparts.

Scholars of international political economy have explored how carmakers' strategic responses to climate change have varied according to their domestic institutional contexts. David Levy and Sandra Rothenberg, for example, argue perceptions on climate science have shaped car companies' strategies for climate mitigation, with US companies like Ford publicly and aggressively challenging the need for binding international CO2 emission controls.[42] In relation to the Bill Clinton administration's Climate Change Action Plan, detailing an annual improvement of fuel economy by at least 2% over a period of 10-15 years, Ford warned its investors that the company would have to "take various costly actions that would have substantial adverse effects on its sales volume and profits."[43] By 1999, Ford further framed climate change mitigation as a "regulatory risk" for its business.[44] According to Levy and Rothernberg, European companies have been less publicly vocal, instead accommodating regulatory demands for significant emissions reduction, as exemplified by the German Automobile Industry Association's (VDA) 1994 agreement to reduce CO2 emissions from new cars by 25%. Levy and Rothenberg

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[41] By avoiding carbon taxes, carmakers could potentially construct more fuel efficient cars or cars running on low-carbon fuels, whereas coal, oil and gas companies cannot change the carbon content of their products. A carbon tax could, perhaps, also cause substantial cost increases for carmakers if the tax targeted coal, a key component in producing steel, which in turn is used to construct car bodies.

[42] Levy and Rothenberg, "Heterogeneity and Change."

[43] Ford Motor Company, "FY93," 22.

[44] US SEC, "Ford Motor Company 10-K, 1999."

ascribed these differences in corporate responses to their different regional institutional frameworks: the US political process has been described as adversarial and legalistic, whereas European political processes have been characterised by tripartite bargaining and rely on intergovernmental consensus.[45] As the next section discusses in detail, US carmakers have historically produced large, fuel-demanding cars for the US consumer market, which could provide another explanation of US producers' more hostile position on climate change relative to their European and Japanese counterparts.

In his seminal study on "greening the car industry," political economist John Mikler adopted an institutional and varieties of capitalism approach to explain national car industries' positions on climate change.[46] Citing public statements, regulatory emissions performance data, and interviews, Mikler found that firms in coordinated market economies (CMEs), characterised by cooperation between firms and regulators, i.e. Japan (Toyota) and Germany (Volkswagen, BMW), have better internalised environmental externalities than firms in liberal market economies (LME), i.e., the US (Ford), which typically develop their strategies to match market demands and generally have a more contentious relationship with regulators.[47]

The 2015 Dieselgate scandal called published emissions data into question and motivated closer analyses of cars and climate change. Historian Mattias Näsman traced the development of international regulatory emission standards in Europe and found that

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[45] Levy and Rothenberg, "Heterogeneity and Change."

[46] On the original Varieties of Capitalism framing, see: Hall and Soskice, eds. *Varieties of Capitalism.*

[47] Mikler, *Greening the Car Industry.*

the technical, scientific, regulatory and competitive underpinnings of these standards have diverged from those of US standards since the 1960s, due to different compromises made in and between nationally specific knowledge creation systems. Näsman's findings underscore the problems of relying on published emissions performance data, which lack transparency, are not easily comparable, and often do not represent actual road performance.[48] Motivated by economies of scale, multinational carmakers typically work to optimise their product ranges across markets with diverse regulatory requirements, subjecting export-oriented manufacturers to conflicting pressures. In joint work, Bergquist and Näsman used the case of Swedish Volvo to show that, because of the company's export orientation, regulations in export markets had an equal or greater role in shaping Volvo's environmental and innovation strategies than regulations in its home market.[49] While many European producers, the subsidiaries of American companies like Ford Europe and GM Europe, and Japanese carmakers have all historically been export oriented, US Ford, GM and Chrysler have sold the absolute majority of their cars on the US domestic market. As a result, carmaker positions on environmental and climate regulations tend to align with those of their largest consumer markets.[50] Carmakers have also used national and international peak level associations, such as the German VDA, Swedish Association of Car Manufacturers and Importers, and the European Committee for Common Market Automobile Constructors (CCMC), to exercise political power when

[48] Näsman, "The Political Economy."

[49] Bergquist and Näsman, "Safe before Green!"

[50] Näsman, "The Political Economy", 312; Bergquist and Näsman, "Safe before Green!," 82.

trying to shape regulation and markets because, as Neil Rollings has shown, the collective action of business interest associations augment business power.[51]

ii. Indirect Climate Action before Climate Politics: Fuel Efficiency and Alternative Fuels

Even before the entrance of climate change into political agendas in the late 1980s,[52] carmakers responding to various pressures indirectly addressed one important aspect of cars' climate impacts, namely fuel consumption. In the interwar period, European producers responded to regulatory pressures, such as domestic fuel and "horsepower" taxes initially introduced as protectionist policies against US carmakers, by designing smaller, lower-powered, and more fuel-efficient cars than those of their US competitors. Behind high tariff protections, US producers meanwhile constructed large and powerful cars to serve their larger and more affluent domestic market. Between 1950 and 1957, the average horsepower of US car engines more than doubled from 111 to 237.[53] Consumers did not always prefer added horsepower and weight, however. As the historian Tom McCarthy has shown, US consumers began trading out large, US-made "gas-guzzlers"' for smaller European cars of higher quality in the latter half of the 1950s. European imports and American Motors' comparably small Rambler model captured 14% of the market in 1959. In response, the "Big Three" US automakers introduced

[51] Rollings, "The Vast and Unresolved"; idem, "Transnational Business Associations." For recent studies focusing on national and international peak-level associations and car emissions policy in Europe, see Ballor, "Liberal Environmentalism;" Näsman and Pitteloud, "The Power and Limits;" Näsman, "The Political Economy;" Klebaner and Ramírez-Pérez, Managing Technical Changes."

[52] Bodansky, "The History."

[53] Wilkins, "Multinational Automobile Enterprises," 238.

“compacts,” cars smaller than the usual US models but slightly larger than European imports, which managed to stave off imports until the mid-1960s.[54] After a brief period, US-made cars increased in size again, while European and, specifically, Japanese imports picked-up speed on the US market.[55] This trend accelerated in the 1970s when the Oil Crises of 1973/4 and 1978/9 limited petrol availability and raised petrol prices, motivating American consumers to look for smaller, more fuel-efficient cars. In the wake of the crises and in response to market pressures, US manufacturers increasingly prioritised fuel economy and small, fuel-efficient Japanese models became increasingly popular. The US car industry invested $80 billion in the development of new fuel-efficient cars, $45 billion of which was contributed by General Motors alone.[56] Importantly, environmental activism also surged globally in the 1970s, augmenting market pressures on the car industry to produce smaller, more fuel-efficient models.

Governmental regulation also drove carmakers to develop fuel-efficient cars. In 1975, the US Congress adopted the Energy Policy and Conservation Act, which mandated carmakers to meet corporate average fuel economy (CAFE) standards by 1978. Japan adopted mandatory fuel economy standards in 1979 as well with implementation in 1985.[57] In Europe, some governments set temporary speed limits, rationed fuel and closed traffic on weekends to mitigate the effects of rising fuel prices. While no European

[54] McCarthy, *Auto Mania.*

[55] Wilkins, “Multinational Automobile Enterprises,” 239.

[56] Jones, *Maturity and Crisis.*

[57] Iguchi, *Divergence and Convergence.*

country introduced mandatory fuel economy standards, some like Sweden and the UK adopted voluntary fuel economy standards in collaboration with the car industry and regulatory agencies.[58] Such fuel conservation efforts were complicated by the fact that in the late 1960s and early 1970s, governments in the US, Europe and Japan had begun implementing standards for controlling pollutant emissions as mechanisms for competition, national economic protectionism, and highly salient issues of public health and safety. Because of the technical tradeoffs of controlling exhaust emissions and increasing fuel economy, the oil shock of 1973-74 put the goals of energy conservation and clean air in conflict, since most technologies carmakers used to control emissions also increased fuel use.[59]

Carmakers in Europe also responded to rising fuel prices and governmental concern for energy conservation and air pollution mitigation by introducing new technologies. In particular, European manufacturers began equipping cars with diesel engines more fuel efficient than petrol ones. Having been used almost exclusively in heavy-duty vehicles, diesel-fueled passenger cars made significant inroads in European and US markets in the late 1970s and early 1980s.[60] Since the 1990s, European carmakers such as Volkswagen, Peugeot-CSA and Renault,[61] pursued diesel technology, made possible by the European Economic Community's (EEC) relatively less stringent emission standards

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[58] Sorell, "Fuel Efficiency"; Näsman, "The Political Economy," 241.

[59] For a detailed account of this, see, Näsman, "The Political Economy."

[60] Neumaier, "Eco-Friendly."

[61] Berggren et al., "Hybrids, diesel or both?"

for emissions of oxides of nitrogen (NOx) in general, and even less stringent for diesels compared to petrol-powered cars. EEC policymakers and the car industry mutually reinforced the diesel trend in relation to the binding emission reduction targets set by the UNFCCC's Kyoto Protocol, when the supranational executive body of European Commission and the newly reconstituted European sectoral business interest association, the European Automobile Manufacturers Association (ACEA), struck a voluntary deal to reduce average carbon emissions – and consequently average fuel consumption – from new cars in 1998. As a result of the deal, diesels increased from 25% of sales in 1998 to roughly half of EU sales between 2006 and 2015. Since the 2015 Dieselgate scandal, which uncovered carmakers' use of electronics to cheat regulatory emission tests, diesels have fallen out of favour even in the European diesel stronghold, dropping to just 23% of market share in 2021.[62]

As early as the 1970s, carmakers began searching for alternatives to potentially replace oil products as transportation fuel. Swedish Volvo and Ford Motors invested in both methanol production and engine adaptation to run on the new fuel. Most investments in alternative fuels stopped, however, when oil prices plummeted in the first half of the 1980s, revealing the contingency of petrol alternatives on fuel prices and consumer demands.[63] Policy effects on alternative fuel prices also shaped carmaker strategies. Beginning in 1975, the Brazilian military dictatorship's ethanol program, which focused on replacing oil imports with ethanol and to provide an additional market for Brazilian sugar,

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[62] Hooftman et al., "A Review"; ICCT, *European Vehicle Market Statistics.*

[63] Mårald, "Methanol as Future Fuel"; Nichols, "The Methanol Story."

motivated automakers there to continue to invest in petrol-alternative technologies. European firms producing in Brazil, including Italian Fiat, German Volkswagen and French Renault, and US firms such as GM and Ford began manufacturing cars powered exclusively by ethanol beginning in 1980 when Brazil's government offered state subsidies to make ethanol cheaper than petrol, regulators relaxed low level blend-in requirements for ethanol in petrol, and sales tax was lowered for ethanol-fueled vehicles. Consequently, by the middle of the 1980s, more than 90% of all new cars produced in Brazil were equipped with ethanol-fueled engines. In 1989, the program to produce ethanol-fueled cars lagged ethanol supply, and as oil prices fell, registrations of ethanol-fueled cars plummeted. The then democratic Brazilian government responded by extending tax subsidies to cars equipped with flex-fuel engines, which could run on petrol, ethanol, or a mix of both.[64]

iii. Toward Heavier, Larger, and More Expensive Cars

Because the 1978 US CAFE fuel economy standards for light trucks were laxer than those set for passenger cars, US consumer preferences substantially shifted toward light trucks, such as minivans, pickup trucks and sport-utility vehicles (SUVs), an unintended consequence of the standards.[65] According to historian Elisabeth Bini, new forms of consumerism emerged in the second half of the 1970s, marked by virulent individualism and a firm belief in both the right to access consumer goods – like petrol – in a free

[64] Amatucci and Spers, "Institutional."

[65] Godek, "Regulation of Fuel Economy."

market and a scepticism of federal regulations trying to limit personal transport.[66] In the US, these views motivated buyers to increasingly choose light trucks over smaller passenger cars in the 2000s. Ford, in particular, led this general reorientation toward producing and selling light-trucks, exemplified by its F-150 pickup truck, which has claimed the title of best-selling vehicle in the US every year since 1981.[67] Although oil prices have remained relatively high for the last two decades, which had the potential to orient consumers toward smaller and more fuel-efficient cars, interest rates remained relatively low after the Global Financial Crisis and Great Recession of 2007-2009 until the aftermath of the Covid-19 pandemic, instead lowering the costs of leasing and purchasing expensive light-trucks. Carmakers are keen on selling light trucks, too, because their profit margins are much larger than those of sedans or wagons. Production costs are marginally higher for larger vehicles, but dealership prices are also substantially higher.[68] Profit margins on individual models are usually closely guarded industry secrets, but estimates suggest that full sized pickup trucks cost an average of $45,000 in 2018, with a profit margin of roughly 25%, whereas the average price of a mid-size sedan was around $22,000, with a mere 10% profit margin.[69] Light trucks accounted for a third of all passenger car sales and leases in the US in 1990, close to half in the 2000s, and a staggering 79% in 2022.[70] By retaining the leniency of CAFE standards toward light trucks

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[66] Bini, “Back to the Future,” 285-286.

[67] Luke, “SUVs”; Talay, “The Ford F-150.”

[68] Snyder, “Crossovers.”

[69] Talay, “How the Ford F-150.”

[70] US BTS, *National Transportation Statistics.*

and keeping petrol taxes low, US regulators have contributed to legitimising the trend toward larger cars. Modest gains in lowering the car fleet's climate emissions have been achieved despite increasing size. Between 2005 and 2021, US manufacturers reduced average CO2 emissions per mile by 25%. In comparison, between the adoption of the CAFE standards in 1975 and until 1987, CO2 emissions decreased by 41%, and even increased by 14% between 1988 and 2004.[71]

In addition to the macroeconomic factors behind the increasing size of cars, regulations in Europe also legitimised the making of heavier and larger cars, as technology scholar Tommaso Pardi has shown.[72] After carmakers failed to meet the CO2 emission reduction targets established in the 1998 voluntary agreement, the EU set mandatory standards in 2009. These standards, however, were differentiated by weight, meaning that carmakers with a legacy of marketing large and heavy vehicles, notably Daimler Benz and BMW, were subject to less strict norms, thus disincentivizing meeting emissions goals by reducing vehicle size. While maintaining or increasing vehicle weight, carmakers' only option for reducing CO2 emissions in the early 2000s was to use diesel and direct injection gasoline engines, both premium technologies. Moreover, as Pardi explained, those technologies made use of advanced electronic controls that provided new opportunities for optimising regulatory emission tests. The sport-utility vehicle (SUV) in

[71] Hula et al., "EPA Automotive Trends Report."

[72] Tommaso Pardi, "Prospects and Contradictions."

Europe, similar to light trucks in the US, has been the only expanding vehicle category in Europe, growing eightfold since 2000 and comprising 51 % of new registrations in 2023.[73]

Not only did carmakers not have to trade increased efficiency for lower climate impact, but consumers also demanded larger and more powerful cars, valued for their higher occupancy and increased safety features relative to smaller cars. Although large cars and light trucks have created new revenue streams for carmakers, they have also been a major driver of increasing carbon emissions.[74] The US Environmental Protection Agency acknowledged that the light truck-trend "has offset some of the fleetwide benefits that otherwise would have been achieved," if only support for smaller and more fuel-efficient cars had been stronger.[75]

iv. Toward a Green Transformation?: The Return of the Electric Vehicle

Under regulatory pressures, the global car industry is progressively shifting away from a dependence on petroleum toward electric vehicles. Although the industry has explored several technological options as replacement for petrol and diesel engines, such as engines using biofuels or hydrogen (fuel cells), government intervention has pushed carmakers to settle on electrification for now. Tellingly, at BMW Welt in Munich in 2024, nearly all car models on display are electric vehicles (EVs), with one hydrogen SUV and just a few remaining ICEs. Global EV sales, including both battery cars and plug-in

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[73] Padeanu, "More Than Half"; ICCT, *European Vehicle Market Statistics.*

[74] Bergquist and Näsman, "Safe before Green!", 79-81.

[75] Hula et al., "EPA Automotive Trends Report," 17. C.f. Pardi, "Prospects and Contradictions."

hybrids, have grown exponentially over the last decade, thanks in large part to government subsidies and incentives. For now, EVs dominate the petrol-alternative market; global EV sales increased from 120 thousand in 2012 to 10.2 million in 2022, accounting for 0.2% of global sales in 2012 and 14% in 2022.[76] In 2024, EV producers facing tight global competition started to look for down-market growth opportunities by making lower cost EVs. EVs promise "zero" greenhouse gas emissions, since they do not use ICEs powered by fossil fuels. EV critics, however, point to the environmental costs of their production and the problem of disposing of used lithium-ion batteries in an environmentally safe way.[77] As explained above, Toyota's leadership remains cautious about the future of EVs, especially in the US. Consumer studies have also noted the relatively weak position of EVs in big markets like the US and Europe, where anxiety about inadequate charging infrastructure has undermined aggressive governmental policies aimed at promoting EV adoption.[78] Finally, some observers argue that hydrogen fuels could play a much more important role in the future, potentially displacing EVs.[79]

The recent breakthrough of EVs on international markets obscures the technology's long history. Individual inventors, carmakers and governments have been experimenting with and innovating EV technologies for over a century. According to Matthew Eisler's recent book on the EVs, the technology's history has been marked by a series of "false starts."[80]

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[76] IEA, *EV Data Explorer*.

[77] Riofrancos et al., "Achieving Zero Emissions."

[78] See, for example, Buchholz, "Electric Cars."

[79] See Greimel. "Toyota."

[80] Eisler, *Auto Electric.*

A substantial body of literature has studied the long historical development of EVs, focusing especially on the period of EV development between the 1880s, when the German Flocken Elektrowagen was introduced, and the 1920s, after which petrol-powered cars had achieved total market domination.[81] Scholars have offered various explanations for why electric vehicles initially "lost" the competition against fossil fuel-powered cars and ICEs. In their review of this literature, economic historians Josef Taalbi and Hana Nielsen noted that explanations have focused on three technological, cultural, and practical factors: the technical inferiority of EVs (low operating range, bulky batteries accounting for much of the vehicle weight, and higher production costs); socio-cultural dynamics (the prioritisation of speed and individualism over reliability and low pollution, the gendering of EVs as female and petrol vehicles as male, that EVs were marketed to the upper class and petrol cars to mass-markets); and the lack of electricity and charging infrastructure outside of large cities.[82]

After 1920, carmakers focused on the production of petrol-powered cars. Then, in response to growing environmental and energy concerns in the 1960s and 1970s, large manufacturers, firms in auxiliary businesses such as electricity generation, and independent entrepreneurs all dabbled with EV experiments again, either by developing new electric cars from scratch or in installing electric motors in adapted petrol models. Investments were small overall, however, and production of EV models remained very low, rarely exceeding a few thousand units.[83] As innovation scholars Robin Cowan and

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[81] Flink, *The Automobile Age*; Kirsch, *The Burden of History*; Mom, *The Electric Vehicle.*

[82] Taalbi and Nielsen, "Energy infrastructure."

[83] Westbrook, *The Electric Car,* 20-27.

Staffan Hultén have argued, most of these EV development projects rested on the assumption that battery capacity and performance could be improved rapidly – and that the fate of EVs was contingent on technological advancements. The requisite improvements to make EVs competitive against ICEs did not materialise quickly, however.[84] Because of batteries' relatively low capacity for energy storage, EVs were plagued by low performance (low range, low top speeds) and high costs compared to conventional ICE cars. Investment in research and development (R&D) for EVs remained low, dwarfed by investments in fossil fuel technologies, although the US Congress, for example, did provide $160 million for the development of batteries through the 1976 Electric and Hybrid Vehicle Research Development Act, and the US "Big Three" carmakers collectively invested $80 billion to downsize and increase the fuel economy of petrol-powered cars.[85] Throughout the twentieth century, skewed investment patterns, reflecting public concern about energy supplies/costs and the environment, favoured petroleum-based technologies and slowly made conventional ICEs cleaner and more efficient, thus maintaining the performance gap between petrol and diesel cars relative to EVs.[86]

More recently, the Chinese government embraced EVs in its Development Plan, through which it supported domestic EV producers, such as BYD – which has transformed from the "laughingstock" of the industry into a global market share leader – and NIO, which

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[84] Cowan and Hultén, "Escaping Lock-In," 70.

[85] Cowan and Hultén, "Escaping Lock-In," 75, 69.

[86] Cowan and Hultén, "Escaping Lock-In," 75.

similarly claims considerable domestic and international market share; Chinese carmakers like these produced about 60% of global electric vehicle sales in 2022.[87] The growth of Chinese EV production and global market share accelerated when China responded quickly to regulatory actions in international markets, including the European Union's (EU) 2022 decision to prohibit the sale of ICEs by 2035, with the important caveat that it will still allow ICEs running strictly on electro fuels – i.e., petrol made from hydrogen and captured CO2.[88] Such developments motivate the following discussion of industrial policy and electric vehicles.

v. The Role of Government Policy and the Issue of Climate Change

The contemporary rise of EVs has a much shorter chronology than the longer history of EV competition with the ICE and is connected to the technological development of batteries since the 1980s, as well as the development of clean air regulations and the emergence of the issue of climate change in the 1990s.[89] In short, the rise of EVs is the result of both technological advancements and government regulatory and incentive interventions.

There are two types of batteries, or battery cells: primary and secondary. Primary cells are not rechargeable and are hence less viable for powering cars,[90] whereas secondary

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[87] Bradsher, "How China Built BYD"

[88] EU, Regulation 2023/851.

[89] Eisler, *Auto Electric.*

[90] In the early twentieth century, car companies set up exchange-charging service systems in various cities in the US that allowed car owners to replace their low-charged batteries with fully charged ones. Similar service systems for replacing exhausted non-rechargeable batteries with new ones is of course imaginable.

cells are rechargeable and a better fit for car use. The first rechargeable battery cell, made of lead-acid, was invented by the French physicist Gaston Planté in 1859; after modifications to make it lighter, it was used in the first vehicles, including in streetcar experiments by Nicholas-Jules Raffard in 1881, and then by the Electric Vehicle Company, founded in Philadelphia in 1886.[91] Lead-acid batteries are still used for lighting and ignition in virtually all cars. Nickel cadmium batteries were invented in 1889 and have been used extensively in high-powered consumer devices such as electric razors and gardening tools since the 1960s.[92] Both of these rechargeable battery types have relatively low energy densities, advancement of which has been slow: doubling from 25 watt hour per kilogram (Wh/kg) to 55 Wh/kg between 1900 and 2010; moreover, cadmium batteries have negative environmental consequences and have consequently lost significant market share.[93] In comparison, petrol has an energy density of 12,700 Wh/kg. Although EVs are more efficient in transforming energy into motion than petrol cars (with conversion rates of 77% for EVs and 12-30% for petrol cars),[94] EV producers have needed to compensate by installing heavy battery packs in order to achieve driving ranges comparable to a petrol-powered ICE, especially given slow investment in charging infrastructure. Batteries typically account for roughly 25% of EV weight (544kg

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See Mom, *The Electric Vehicle*, 230-234. Eisler also hinted that the intentions by GM's battery partner, Ovonic, aimed at constructing a market for disposable primary batteries for EVs similar to the consumer electronics market in the early 1990s. Eisler, "Public Policy."

[91] Mom, *The Electric Vehicle,* 10, 79-93.

[92] The Economist, "The Perfect Battery"; Wittingham, "History."

[93] Zu and Li, "Thermodynamic Analysis," 2615.

[94] U.S. DOE, "All-Electric Vehicles."

out of a total 2160kg for the Tesla Model S, for example), while the gasoline engine and battery of a luxury Nissan Maxima V6 weigh 120 kg and 20 kg respectively out of a total weight of 1925 kg.[95] Other challenges include making batteries operational at ambient temperature, modifying the composition of batteries through the use of various materials, and increasing energy storage while maintaining battery life.[96] Building on chemical breakthroughs in the 1960s and 1970s, notably by scientists at the Ford Motor Company and Exxon, new rechargeable batteries hit the market for consumer electronics in the late 1980s, namely nickel-metal-hydride batteries and lithium-ion batteries, with respective energy densities of 50-80 Wh/kg and above 210 Wh/kg.[97]

The "performance argument" that EVs lost the automotive race to fossil-fueled engines because of lower speeds and range, has been challenged by Kirsch and Mom, and more recently by Eisler.[98] Eisler highlighted a "temporal mismatch" in EV technology: that batteries have a shorter life compared to electric motors required finding ways of servicing and replacing batteries during a car's operational lifespan. Traditional car manufacturers, moreover, were reluctant to switch from ICEs to EVs in the late twentieth century, because their business models rely on revenue from servicing and providing spare parts for ICEs.[99] Since battery cell production was a separate line of business and dominated by Asian

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[95] Ritchie, "The Weighty Issue."

[96] Wittingham, "History," 1521 f.

[97] Wittingham, "History," 1521 f.; Zu and LI "Thermodynamic Analysis," 2615.

[98] Kirsch, *Burden of History;* Mom, *The Electric Vehicle*; Eisler, *Auto Electric.*

[99] Eisler, *Auto Electric,* 9.

firms, traditional carmakers were at risk of losing a substantial and profitable stream of revenue by embracing EVs.[100]

Ultimately, governmental policies, specifically in California, the world's largest car market, fueled the rise of EVs starting in the 1990s. Notably, the emergence of batteries gained prominence in 1997 when Toyota introduced the Prius hybrid model, equipped with nickel-metal-hydride batteries, in the Japanese market. In 2000, Toyota launched the Prius globally with great success in the US market. Honda followed Toyota's lead, launching the Insight model in Japan in 1999 and internationally in 2001.[101]

In 1990, before the launch of the Prius and Insight models, the California Air Resource Board (CARB) adopted its Low Emissions Vehicle program requiring major carmakers to sell vehicles with zero pollutant emissions. Aiming to combat the air pollution problem that had plagued California for several decades, the state initially required 2% of total car sales to be zero emission vehicles in California from 1998, with a planned increase to 10% in 2003.[102] Under continued lobbying and litigation pressure, especially by firms such as GM and Ford, CARB modified the regulation several times and created additional vehicle categories.[103] Between 1999 and 2003, CARB delayed the deadline by two years, allowing carmakers in the California market – like the US "Big Three" and Japanese Toyota, Nissan, Mazda, and Honda – to comply with the mandate by offering hybrid-

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[100] Eisler, *Auto Electric,* 9.

[101] Yarime et al., "The Strategies."

[102] Collantes and Sperling, "The Origin."

[103] Eisler, "Public Policy"; Fredrickson, "Ecostar."

electric and hybrid-fuel-cell vehicles.[104] Although numerous manufacturers showcased electric and hybrid vehicles to meet the program's criteria, many of these models remained experimental concepts and were not intended for commercialisation. Examples include GM's Impact and Ford's Ecostar, which were primarily developed to contest CARB's policies.[105] Companies adopted what Eisler has called "better battery discourse," by arguing that contemporary batteries could not match the energy and cost of petrol engines.[106]

The 1990 California zero-emissions policy motivated Japanese companies reliant on the US market, such as Toyota, Nissan, Honda and Mazda, to make substantial R&D investments in electric and hybrid-electric vehicles and hydrogen fuel cells, as research on patent data has shown.[107] Already in 1976, the powerful Japanese Ministry of International Trade and Industry (MITI) adopted policies to support EV production and marketing to mitigate oil-dependence and emissions. As the oil market stabilised after the turbulent 1980s, MITI's plans for expanding the EV market waned until the shock of Iraq's 1990 invasion of Kuwait nearly doubled the crude price per barrel. Faced with high petrol prices, the new California zero-emissions policy, the Rio Summit in 1992, and a growing global concern about climate change, MITI refocused on supporting the construction of charging infrastructure as well as market incentives for clean vehicles.[108] Because of their

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[104] Wesseling et al., "Exploring."

[105] Eisler, "Public Policy," 786; Fredrickson, "Ecostar," 139-144.

[106] Eisler, *Auto Electric,* 5-6.

[107] Yarime et al., "The Strategies."

[108] Åhman, "Government Policy."

limited domestic market, Japanese producers remained export oriented and anticipated international regulations and consumer preferences for EVs well.

Several scholars have studied Toyota's development of the Prius, which reflects the evolution of corporate environmentalism and how public and corporate perceptions of business responsibility for addressing environmental challenges changed in the late 1980s and 1990s.[109] Masaru Yarime and colleagues noted that Toyota was aware of its perception as an environmental laggard in the 1970s compared to the efforts of Honda and Mazda to address air pollution.[110] Wanting to change this negative image, Toyota set up an environmental committee chaired by the company's president in 1992, and published a global environmental charter in 1993, following the general trend of multinational corporations in the 1990s to boost green communication, now often criticised as "greenwashing."[111] In 1993, Toyota set up a concept study, called the Global 21st century (G21) committee, which outlined visions for the company's planned advanced propulsion vehicle. Based on projections of future oil supplies and increasing petrol expenses, the G21 committee set the goal of improving fuel efficiency by 50%. Pure battery-drive was ruled out as too expensive for commercial advanced propulsion vehicles, but a direct-injection petrol engine could meet the fuel efficiency target, thereby reducing both consumer fuel costs and the amount of petrol burned by passenger cars, consequently minimising car emissions. In 1994, Toyota management responded to

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[109] Magnusson and Bergren, "Environmental Innovation." Yarime et al., "The Strategies"; Eisler, "Public Policy."

[110] Yarime et al., "The Strategies."

[111] Bergquist, "Renewing Business History."

these findings by requiring engineers to double fuel economy or it would end the G21 program. Because realising such a fuel economy goal was not possible using conventional engines, the committee began testing new technologies and settled on electric-petrol hybrid technology, which the company had developed for a sports vehicle already in 1977.

Toyota's development of the Prius was largely kept secret until the model's production launch, timed to coincide with the third climate change conference (COP 3) in 1997, hosted by Japan.[112] While it is clear that regulatory pressure was a key driver of the innovation and the commercialisation of hybrids, especially in relation to California's zero emission vehicle mandate, other policies reinforcing technological shifts toward radically more fuel-efficient cars were generally lacking. Consequently, as Table 1 (below) shows that petrol-electric hybrids, like the Prius, achieved relatively marginal market share in the 2000s, except in Japan, where they made up over 10% of sales by 2010.

As Table 2 (below) makes clear, global car markets shifted toward electrification in the late 2010s and early 2020s, when industrial policy fueled the rise of EVs. But the road to zero carbon emissions has not been straightforward. First, in 2021, electricity generated from fossil fuels accounted for 60% of electricity generation in the US, 67% in Japan, 77% in China, and 39% in the EU.[113]

[112] Eisler, "Public Policy," 799; Kameyama, *Climate Change Policy,* 49.
[113] IEA, "Energy Statistics Data Browser."

Table 1. Annual passenger car registrations/sales (in million units) and share (%) of gasoline-electric hybrid passenger cars in USA, Europe, Japan and China 2000-2010

	2000	2002	2004	2006	2008	2010
USA[a]	17.4 (<0.1%)	16.8 (0,2%)	16.9 (0,5%)	16.4 (1,6%)	13.3 (2,9%)	11.6 (2,1%)
Japan[b]	4.3 (…)	4.4 (…)	4.8 (…)	4.6 (…)	4.2 (2,6%)	4.2 (11,4%)
Europe[c]	15.4 (0%)	15.0 (0%)	15.2 (0,1%)	15.4 (0,3%)	14.3 (0,5%)	13.3 (0,6%)
China (NEV)[d]	…	2.3 (…)	…	4.7 (<0.1%)	6.2 (<0.1%)	12.5 (<0.1%)

[a] New vehicle sales include passenger cars and light trucks as well as leases. [b] Information for hybrid sales for Japan is only available from 2008. [c] EU 27 includes the UK but not Croatia. The first entry for Europe is from 2001. [d] New energy vehicles (NEV) include hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, and fuel cell vehicles.

Source: Japan: JAMA, *The Motor Industry,* various years. Europe: ICCT, *European Vehicle Market Statistics*, various years. USA: US BTS, *National Transportation Statistics*. China: China Statistics Press, *China Statistical Yearbook,* for registrations. For NEV share, see, Stegrin, *China Automotive Industry,* 15.

While EVs are more efficient than ICEs in transforming fuel to motion power, the high fossil content of electricity offsets some of the potential climate gains from an EV transition than otherwise could have been possible by charging EVs with renewable energy. Second, the data include both plug-in hybrids and battery electric cars. Emissions from plug-in hybrids are dependent on drivers keeping the battery charged to minimise reliance on the ICE. Studies by the International Council on Clean Transportation (ICCT), however, suggest that drivers do not sufficiently charge the batteries to keep emissions low, and that real-world emissions from hybrids are close to ICE cars.[114] According to the International Energy Agency (IEA), plug-in hybrids made up 44% of EV registrations in

[114] Plötz et al., *Real-World Usage.*

the EU and 40% in Japan in 2022, whereas they comprised only 25% in China and 19% in the US.[115] The seemingly widespread transition toward EVs could be a powerful tool in mitigating climate change, but only with a parallel decarbonisation of the utilities sector providing energy to recharge EV batteries.

Table 2. Annual passenger car registrations/sales (in million units) and share (%) of EV sales (including plug-in hybrid and battery electric cars) in USA, Europe, Japan and China 2010-2022

	2010	2012	2014	2016	2018	2020	2022
USA[a]	11.6 (<0.1%)	14.5 (0.4%)	16.5 (0.9%)	17.6 (1.0%)	17.3 (2.0%)	14.6 (2.2%)	13.8 (7.7%)
Japan	4.2 (<0.1%)	4.6 (0.5%)	4.7 (0.7%)	4.1 (0.6%)	4.4 (1.1%)	3.8 (0.8%)	3.4 (3%)
Europe[b]	13.3 (<0.1%)	12.0 (0.2%)	10.0 (0.6%)	12.0 (1.0%)	12.7 (1.9%)	10.0 (10%)	9.7 (21%)
China	12.5 (<0.1%)	15.2 (<0.1%)	19.4 (0.4%)	24.6 (1.5%)	23.1 (4.9%)	19.7 (5.8%)	22.0 (29%)

[a]New vehicle sales include passenger cars and light trucks as well as leases. [b]EU 27, includes Croatia but not the UK.

Note: Last entry on registrations for Europe and China is from 2021.

Source: IEA, *Global EV Data,* for EV sales shares and registrations from sources in Table 1.

III. Climate Racing: Industrial Policy and the Struggle over Electric Vehicle Markets

Since the 2008 Global Financial Crisis, globalisation has been in slow retreat.[116] The Covid-19 pandemic and Russian invasion of Ukraine in 2022 further contracted overseas investment and trade. At the same time, policies for addressing climate change have

115 IEA, *Global EV Data.*

116 On deglobalization trends, see: Baldwin and Evenett, eds. *COVID-19 and Trade Policy.* .

gained prominence in many policy agendas, particularly after the 2015 Paris Climate Agreement. Governments “rediscovered” industrial policy to bolster their industries relative to global competition, often with a green or environmental focus. In 2009, the Obama administration combined policies for supporting the US car industry in the form of bailouts with setting higher fuel economy standards, and earmarked stimulus funds for advanced batteries and vehicles, extending these policies with EV purchase incentives in 2015.[117] Tesla Motors, the exclusively EV carmaker whose name has dominated contemporary discussions of EVs in the West, scaled its business through federal and state support for EVs, including a California program through which it has sold credits to other carmakers who failed to sell sufficient zero emissions cars – and from which it made nearly 9 billion USD.[118] Meanwhile, US policymakers treated Tesla as a national champion, even as other states courted Tesla’s FDI.[119] Tesla’s success motivated technology companies like Apple to invest billions of dollars in developing its own EVs and autonomous driving capabilities – a plan that was ultimately shelved in 2024.[120] Tesla also lobbied Chinese officials to adopt a similar credits scheme as California, a condition it used in negotiating the opening of its Shanghai factory in 2019. In exchange for the 1 billion USD of revenue China has paid Tesla for its EV credits through this new scheme,

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[117] Turner, *Charged,* 137-138.

[118] Trudell, “Tesla.”

[119] Eiseler, *Auto Electric,*chapter 12-13.

[120] Tilley and Colias, “Apple Ends Quest.”

China has benefitted from Tesla's inadvertent training of a generation of Chinese EV engineers and manufacturers.

While the EU only turned its focus to electric vehicles after the Dieselgate scandal in 2015, it has also faced institutional challenges in responding to US and Chinese industrial policy.[121] Since the 1980s and until the mid-2010s, EU economic policy encouraged international and internal competition through market forces, with limited governmental intervention permitted by the anti state aid policies developed to complete the internal Single Market, and competition policy taking a precedence over industrial policy interventions by EU institutions.[122] After the 2008 financial crisis, as the EU lagged the US in technological development, and Chinese companies became globally dominant and increasingly invested in Europe - like Geely's acquisition of Volvo Cars from Ford in 2010 - EU policymakers began arguing for more active state involvement in restoring Europe's industrial competitiveness.[123] The Covid-19 pandemic demanded new economic policy instruments. In 2020, the EU passed the European Green Deal to support industrial development, while aiming to be climate neutral by 2050.[124] In addition to cutting pollution, cultivating an international climate coalition, and securing the region's access to industrial raw materials, the Green Deal aimed to support the R&D of environmentally friendly transport, energy, and industrial production and to position the European car industry to

[121] Klebaner and Ramírez Pérez. "The European Automotive Industry."

[122] On European competition policy, see the work of Laurent Warlouzet, including: "Competition versus Planning," and "The Implementation of the Single Market Programme."

[123] For an overview, see, Jean-Christophe Defraigne et al., "Past Lessons, Current Challenges."

[124] Leonard et al., "The Geopolitics of the European Green Deal;" Meunier and Matthijs, "Europe's Geoeconomic Revolution."

benefit from a green transition. Of course, carmakers took interest in this new policy agenda, especially since the European Commission, the EU's executive body, made explicit its intention to move the EU away from fossil fuels and ICEs by 2035, and, as Anu Bradford has shown, EU policymaking often has a global "Brussels effect."[125] According to the Stellantis CEO, Carlos Taveres, the institutional pressure on EVs has had a clear impact on manufacturer's electrification strategies in Europe: "The regulatory framework is clear: You sell EVs or you die."[126] In 2022, the United States passed the Inflation Reduction Act, which, in addition to curbing inflation, reducing the federal debt, and lowering drug prices, also aimed to promote clean energy and invest in domestic energy production. Similarly, individual US states have begun to use public procurement as a means of implementing local green industrial policy.[127] And in early 2024, the US EPA announced new exhaust emissions requirements aimed at shifting the majority of US cars and light trucks to all-electric or hybrid by 2032, a slight delay from President Biden's initial target of 2030.[128]

This recent "rediscovery" of industrial policy in Europe and the US should be viewed against the backdrop of and in competition with the long and successful industrialisation

[125] Bradford, *The Brussels Effect.*

[126] Motavalli, "Stellantis CEO."

[127]In December 2023, Michigan Governor Gretchen Whitmer signed an executive order requiring the state to convert its fleet of 8,000 trucks and cars to zero-emissions vehicles by 2040. She explained that this was not only a climate-conscious decision, but also a move to support the state's EV industry. Mauger, "Michigan Gov. Gretchen Whitmer."

[128] Biden, "Strengthening American Leadership."

strategy of the Chinese Communist Party (CCP).[129] Once devoid of any car production, China has become the world's largest car producer over the past 30 years. As in other centrally planned economies during the Cold War, commercial vehicles initially dominated Chinese production targets, whereas passenger car production served only the CCP elite. Since the 1980s and in various stages afterwards, the Chinese government has aimed to make the domestic industry more efficient and internationally competitive by encouraging foreign car companies to invest in the Chinese car industry through joint ventures with state-owned enterprises, such as Shanghai Automobile Industry Corporation's joint venture with Volkswagen in 1984.[130]

To sell cars in China, foreign car companies had to produce cars in joint ventures with at least 50% Chinese (state) ownership and additionally had to meet domestic sourcing requirements. To maintain control, the Chinese state limited approval of joint ventures, while simultaneously partnering state-owned enterprises with two foreign companies to bolster internal competition and facilitate technology transfers.[131] It also implemented high tariffs to shield its state owned enterprises, while private domestic companies were kept out of China by high entry requirements. According to Niewnhius and Xiao, the political structure of the Chinese car market created a mutual dependence, in which foreign car makers were dependent on high sales in China's large market, and Chinese partner

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[129] Wenten, "The Automotive Industry"; Nieuwenhuis and Lin, "China's Car Industry." See also the work of Yuan Jia Zheng on the Chinese car industry.

[130] Wenten, "The Automotive Industry," 282

[131] Wenten, "The Automotive Industry," 281.

companies were dependent on foreign technology.[132] Since its accession to the World Trade Organisation (WTO) in 2001, Chinese industrial policy has aimed to resolve the problem of foreign technology dependence through the creation of national brands, as well the development of so-called "new energy" vehicles, cars powered entirely or predominantly by electricity. Forced to open its car market and relax the restrictions on new entrants, the Chinese government gradually granted vehicle assembly permission to four domestic companies until 2003: Chery, Geely, Hafei and Brilliance, and to the battery maker BYD – out of which only Geely and BYD were fully private.[133] The opening of the Chinese car market caused local production to skyrocket in the 2000s, from 700,000 passenger cars in 2001 to 14 million in 2010 and then 24 million in 2022.[134] Private Chinese firms struggled to compete against joint ventures between state owned and foreign companies with well established technological leadership in producing ICE cars. By 2010, private domestic producers claimed only 33% of the Chinese market.[135]

Since no established carmakers had a specific or significant competitive advantage in producing vehicles using alternative fuels or powertrains, the Chinese government recognized the business opportunity of developing new energy vehicles and non-ICE cars like EVs. This Chinese plan began in 2001 with R&D support for pure EVs, hybrid electric, and fuel cell vehicles, as well as key components like multi-energy powertrain controllers,

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[132] Nieuwenhuis and Xiao, "China's Car Industry," 113.

[133] Wenten, "The Automotive Industry," 285; Niewnhius and Xiao, "China's Car Industry," 117.

[134] OICA, "Production Statistics."

[135] Nieuwenhuis and Xiao, "China's Car Industry," 117.

drive motors, and power batteries. In 2006, funding efforts were refocused on key components, reflecting China's place in most global supply and value chains.[136] Despite state support for R&D, however, the Chinese industry's total investments in R&D remained small compared to that of Western and Japanese firms. In 2012, for example, the combined R&D investments by Chinese domestic firms only amounted to roughly 60% of Volkswagen's operations in China, meaning that Chinese carmakers sought to remain competitive through costs rather than technological competition, and domestic brands focused on producing cheap cars.[137] Commercialisation of EVs began in the 2010s, however, largely due to the Chinese government's targets for EV and battery production and its stimulus policies in the wake of the Great Recession, including tax breaks, laxer registration policies for EVs, the building of charging infrastructure, and public procurement of new energy vehicles.[138]

As of now, China's competitive edge in EV production lies in controlling the entire value chain: Chinese mining companies have monopolised access to the strategic minerals used in batteries, as well as mineral processing and refinement.[139] China dominates natural graphite production, currently important for producing anodes; it has the highest capacity of refining lithium and cobalt sulphate; and it also dominates battery component production.[140] China has also worked to command these strategic mineral resources

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136 ibid, 119.

137 Ibid, 117. Cf., ACEA, *Pocket Guide,* 91.

138 Nieuwenhuis and Xiao, "China's Car Industry," 119-124.

139 Business Sweden, *The Nordic Battery.*

140 Business Sweden, *The Nordic Battery,* 50, 65.

through international standards.[141] The CCP's policies and EV production targets further propelled the global rise of Chinese battery companies like BYD and CATL (The Contemporary Amperex Technology Co). In 2021, China housed three fourths of global battery cell production, an industrial policy success similar to China's early dominance in the production of solar panels.[142] Moreover, China has, together with Japan, a competitive advantage in global charging infrastructure, since most car battery chargers use Chinese or Japanese standards.[143]

Although China is leading the world in the transformation of the car industry toward electrification, it is important to keep in mind that the Chinese industry is still mainly producing ICEs, with the capacity to produce 15 million gasoline powered vehicles per year as of 2023. Amid a slumping domestic economy, these Chinese ICE cars have been "dumped" on international markets with lax emissions regulations.[144] Moreover, China's built-up ICE production capacity is not going away as long as demand for fossil fueled cars remains: "What are you going to do, close a factory?" the former executive of Chrysler China, Bill Russo, remarked.[145]

Together, Chinese competition, the challenges of the Great Recession and Covid pandemic, and climate change have motivated many governments in the US and Europe

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[141] On critical mineral standards, see Ballor, "Ruling the Natural World."

[142] Business Sweden, *The Nordic Battery,* 61-62.

[143] Wenten, "The Automotive Industry," 288.

[144] Bradsher, "China."

[145] Bradsher, "China."

to use industrial policy to promote EV production. Many industrialised countries have car industries with strong legacies, in which carmakers became national champions by facilitating industrialisation and modernisation. But a political transformation is now underway to replace fossil fuel-powered cars with EVs. To reach the goal of net-zero emissions from global road transportation by 2050, the IEA has estimated that 30 million EVs need to be sold by 2025 and 70 million by 2030, or a projected 30% and 60% respectively of total vehicle sales.[146] Regardless of the accuracy of those estimates, the dual aims of replacing the ICE but maintaining private motoring are creating demand for EV production volumes that exceed current capacity, making it challenging to determine which firms and countries will benefit the most from this transition. Currently, Western and Asian car firms have a competitive edge in producing larger and high-end EVs, whereas Chinese firms are focusing on smaller and cheaper EVs. Nevertheless, it is safe to say that whoever succeeds in capturing large parts of the growing global market for EVs has a lot to gain. Meanwhile, established firms, national industries, and states with legacies of producing ICE cars that are failing to innovate and transition into EV technologies will face economic losses, which helps explain the widespread resurgence of industrial policy.

That China recently redoubled its support for its national champions prompted the European Commission to launch an investigation into China's subsidisation of EVs, especially through the EV carmaker Nio.[147] These developments in the geopolitical contest of industrial policy and EVs reflect the history of Japanese competition in Europe

[146] IEA, *Global EV Outlook 2023,* 110.

[147] Bradsher, "China's EV Threat."

and the EEC/EU's solution to restricting Japanese exports into its liberalised Single Market through a secretive agreement.[148] The return of industrial policy augments geopolitical tensions, about which the IMF has become concerned.[149]

Developing countries without legacy car industries have also recognized business opportunities in the changing landscape of green transition. For infrastructural, economic, and geopolitical reasons, two wheeled EVs promise industrial development and solutions for personal transportation in countries across Africa and Southeast Asia. 27 million two-wheelers travelled the roads of sub-Saharan Africa in 2022, reflecting the large market for micro-mobility. With the introduction of EVs in Africa in recent years, countries like Kenya have experienced a "Two-wheeled Revolution," shifting from diesel powered motors to electric ones. This revolution developed in parallel to Nairobi's embrace of electric public buses, prompted by Kenya's desire to move toward energy independence and away from its reliance on petrol imports. Kenya's government also celebrated the launch of local manufacturer Roam's new two wheeled EV factory as an economic opportunity for the firm to supply East Africa with clean personal transportation.[150] And Uber announced plans to shift 20% of its fleet in Kenya to electric bikes.[151] Most two-wheeled EV models are green replacements for small motorcycles, mopeds, and scooters. Some, however, like the SHANE, are two-wheeled concept cars in a category

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148 Ballor. "Liberalisation"; Milor, "Non-documents."

149 Irwin, "The Return of Industrial Policy."

150 Gunderson, "Kenya's Two-Wheeled Revolution."

151 Miriri, "Uber Rolls Out Electric Bike Fleet in Kenya."

of their own. These smaller, cheaper EVs have become another battleground for international competition, especially within and between developing countries.[152] In India, for example, the most polluted and densely populated country in the world, two-wheeled EVs can be cheaply produced and promise a path to net zero emissions. Once an iconic petrol motorcycle, the Bajaj Chetak has been redesigned as an EV. Other popular models in India include the Ampere, OLA, and Hero EVs. Even legacy petrol two-wheel producers, like Harley Davidson, BMW, and Vespa have introduced electric versions of their classic bikes and scooters, both cleaner and quieter than the traditional models.

IV. The outcome on global warming

Since the 1970s, efforts by regulators and carmakers to improve fuel economy and embrace new technologies only somewhat reduced emissions from road transportation, nor did they curb the global trend of increasing emissions, largely because widespread automobility became a strong consumer demand and an economic development goal for many governments.[153] Figure 1 (below) shows CO2 emissions from fossil fuels (petroleum) used in road transportation in the US, European OECD countries, Japan and China, and reveals a small slump in emissions in 1974-1975 and in 1979-1982 which coincided with the two oil price shocks and economic recessions. Oil prices trebled in the first oil crisis, applying downward pressure on demand. Similarly, the recession in the early 1990s slightly reduced petroleum demand uniquely in the US and China, while

[152] Gupta et al., "The Real Global EV Buzz Comes on Two Wheels."

[153] On this point, see Bini, "Back to the Future"; Giulio Mattioli, et al., "Car Dependence," Freyssenet, "The Second Automobile Revolution.".

global oil prices kept falling. As a result, carbon emissions from road transportation increased steadily between 1980 and 2007. Low prices kept demand and use high.

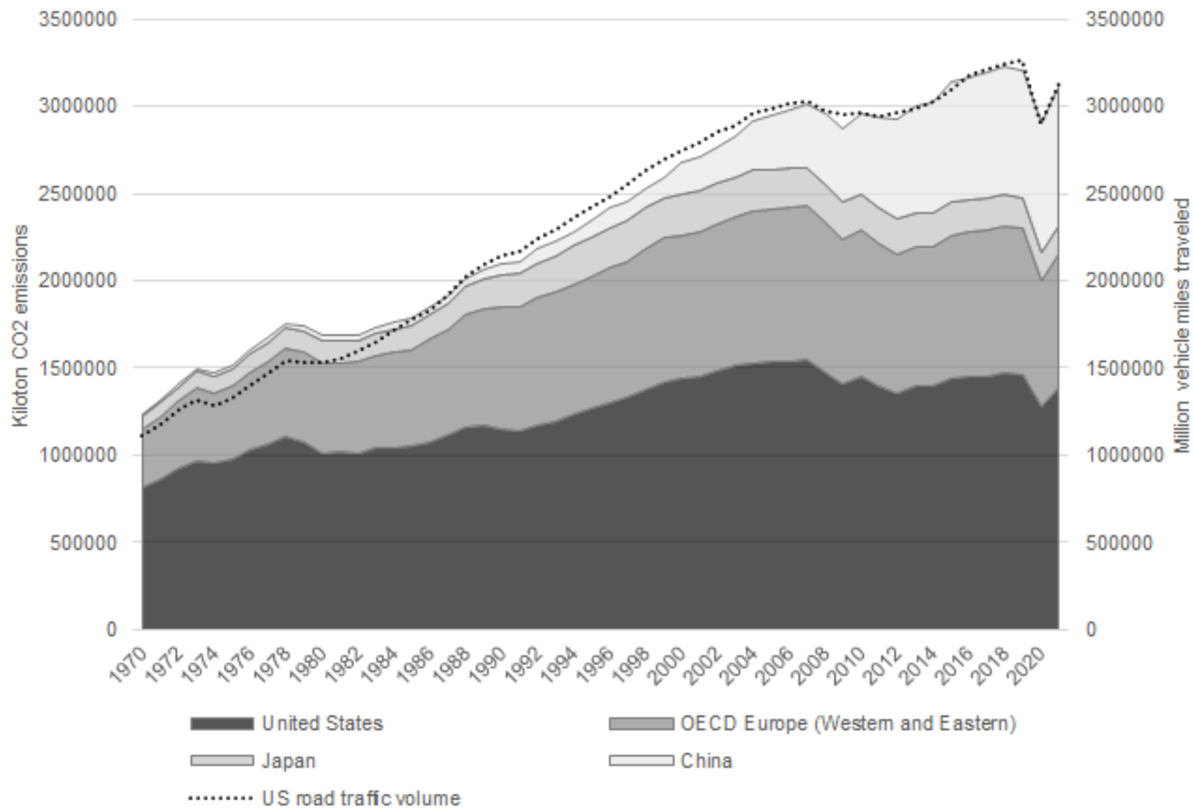

Figure 1. Fossil CO2 from road transportation and road traffic in selected countries, 1970-2021.

Source: For Fossil CO2 emissions, EDGAR database, "CO2 Emissions." For vehicle miles travelled, US, US DOT, Highway statistics series.

So far, the recessions caused by the oil shocks of the 1970s, the Great Recession, and the Covid-19 crisis seem to be the only periods in which fossil carbon emissions from road transportation decreased in absolute terms. After 2007, emissions stabilised across the OECD, including in the US, indicating that fuel efficiency improvements offset the impact of increasing road travel. Car emissions in Japan actually decreased by 25% between 2001 and 2019, which is partly explained by a decrease in road traffic due to stricter regulations on personal transportation and improvements in public transportation infrastructure, but also by the penetration of fuel-efficient hybrids in the Japanese car fleet.

Finding comparable statistics on road transportation is difficult, but by using vehicle miles travelled in the US (the most consistent data) as a proxy indicator, it is possible to draw some tentative but general conclusions about the outcome of efforts to improve car fuel efficiency. By comparing the development of carbon emissions with the development of road traffic, it seems that technological advances in fuel efficiency have somewhat offset the marked increase of road traffic since the early 1980s. As is well known in the economics literature, however, better fuel economy lowers driving costs, which in turn encourages drivers to drive more and longer: the so-called rebound effect.[154] The trend toward larger cars discussed above adds additional roadblocks to reducing the industry's carbon footprint. Despite growing traffic volumes, CO2 emission levels have stabilised below their 2007 peak, but only economic crises and oil price shocks have managed to reduce total emissions. While China, a global latecomer to automobility is focusing most intensively on transitioning to EVs, most of its car production capacity and active fleet remain reliant on fossil fuels.

[154] In this vast literature, see, e.g., Linn, "The Rebound Effect."

V. Conclusions

This business history of cars and climate change shows how the development of alternatives to ICEs and fossil fuels – and the current primacy of EVs – do not reflect the limits of technology, but are instead the outcomes of an entangled history of political choices and business strategies. Likewise, political choices will continue to shape the future of cars and climate change; as governments make industrial policy decisions and champion firms compete for global market share, the resulting geopolitical contest will continue to shape the industry and its impact on climate change. Carmakers will continue to adapt to regulatory and competitive pressures to align their business strategies with the markets in which they operate – markets that are increasingly oriented around policies promoting zero emissions as a key objective for the car industry's "green transition" to mitigate the causes and consequences of climate change.

In a general summary of the period surveyed in this paper, covering roughly 140 years of the history of the car industry and its technological development, it is clear that political choices increased, rather than decreased, the industry's climate impact, until mitigating strategies were adopted in the 1970s. When pressure for limiting fossil fuel use emerged, indirectly, in relation to the oil price hikes of the 1970s and directly in relation to the Kyoto protocol in the 1990s, carmakers' responses diverged by market context. Some carmakers began developing biofuel technologies in the 1970s, while the US "Big Three" focused on making gasoline engines more fuel efficient in response to surging oil prices and regulation; meanwhile, European firms such as Volkswagen, Peugeot-CSA and Renault began developing diesel technologies, considered more fuel efficient for meeting climate goals, and Japanese firms like Toyota chose gasoline-electric hybrids in the 1990s.

In the 2010s, after over a century of “false starts,” regulation and business strategy has converged on EVs, which have long-term potential to lower the car industry’s direct climate impact. Overall, as this paper has explained, the evolution of the political and economic incentive structures for car construction and consumption have presented mixed signals to car makers and consumers. CO2 emissions from road transport have not decreased, except during demand shocks like energy and economic crises and the Covid-19 pandemic. Concurrent with growing public concern about climate change since the late 1980s, there has been an ironic growth in the weight, size, and performance of cars, counteracting efficiency gains. Consumer preferences, profit incentives, and the concurrent lack of comprehensive policies to reduce greenhouse emissions, climate mitigation efforts have not managed to keep pace with the countervalent trends causing emissions to increase.

Twenty-first century electrification of the car industry potentially offers the first real break with this longer trend of increasing emissions. Beginning with regulation in California in 1990, the strategic alignment of climate change mitigation with industrial policy converged on battery-electric vehicles as means of addressing climate change and supporting national champions in the wake of the Great Recession and the geopolitical contest over global car markets.

By historicizing the relationship of business and climate change, this paper has explored industry responses to various climate change mitigation efforts, requisite for understanding how change happens over time and how a wider green transition could develop. We hope it also lays a foundation for further historical research on this topic, much needed by the many think tanks and policy centres now studying the car industry, its evolution, and climate change mitigation efforts.[155]

[155] One example of this is the work of the French Fondation pour la nature et l'homme: https://www.fnh.org/automobile-notre-scenario-pour-transition-juste/

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