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Original research article

The temporal evolution of resistance strategies during low-carbon transitions: Revealing the industry playbook of US, German, and Japanese automakers in the unfolding electric vehicle transition (1990–2025)

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ABSTRACT

Building on research into the types of resistance strategies employed by incumbent firms (including framing, lobbying, organised pressure, and litigation), this article investigates the temporal development of these strategies during low-carbon transitions. Rather than understanding resistance as a temporary phenomenon in early transition stages, we conceptualise it as a dimension recurring over multiple phases. We develop an ideal-type framework of changes in the type and focus of resistance strategies during five phases of low-carbon reorientation, thereby identifying the industry playbook. We apply this framework to three case studies of incumbent automakers in the United States, Germany, and Japan, which since the 1990s have used multiple resistance strategies while reorienting towards battery electric vehicles (BEVs). We find that US automakers resisted strongly from the early 1990s, that German automakers gradually increased their resistance strategies over time, and that Japanese automakers hardly resisted in early phases (because of their reorientation towards hybrid electric vehicles) but strongly resisted BEVs in later phases. We further find that US automakers used more overt confrontational strategies, while Japanese and German automakers relied on less visible lobbying and consultation tactics. Automakers used resistance strategies throughout the entire case study duration but shifted focus in the last period from opposing the *direction* of travel towards resisting the *speed* of change. Although automakers are now significantly reorienting towards BEVs, they continue to use resistance strategies. We explain this paradox by suggesting that automakers play multi-dimensional chess, in which they reorient in some dimensions while resisting in others.

1. Introduction

As the pace of global climate mitigation remains too slow [1], resistance to change has become an increasingly critical research topic with scholars exploring how incumbent firms hamper and delay low-carbon transitions [2–6]. A recent editorial in *Nature Sustainability* [7] also called attention to this topic, announcing the creation of an *International Expert Panel on Overcoming Resistance to enable Sustainability Transformation* scheduled to report in 2025.

The extant literature on sustainability transitions has long recognised that incumbent firms, being locked-in into existing socio-technical regimes, tend to resist transitions because these threaten their vested interests [8–19]. This literature has also advanced different but partially overlapping typologies of resistance strategies. These include *information strategies*, which provide alternative facts or theories to deny or cast doubt on the scientific basis of climate change [18,20]; *framing strategies*, which advance claims aimed at shaping public or political debates, e.g. that low-carbon technologies are immature, unfeasible, too expensive, or undesirable and that particular policies or courses of action would have negative consequences for the industry and associated jobs [2,21]; *lobbying strategies* through which firms shape policy-making from within, including through revolving door mechanisms, close consultation or participation in rulemaking platforms [22,23]; *confrontational strategies* like litigation and lawsuits against policymakers [24]; and *organised*

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pressure strategies, in which incumbent firms create associations or coalitions like the Global Climate Coalition in the US [25] that speak and lobby on behalf of the entire industry.

While this mapping of various resistance strategies in recent years is an important achievement, the temporal understanding of how different resistance strategies are applied over time is under-developed. Scholars implicitly or explicitly tend to locate resistance strategies in the early phases of sustainability transitions [3,13,26], when external pressures (from activists, scientists, or policymakers) destabilise or open up existing regimes, forcing incumbent actors to address sustainability problems. This understanding often builds on Lewin's [27] three-step model of change ('unfreezing-change-refreezing'), where the first step of unlocking existing structures often invites resistance. Béné and Abdulai [26], for example, locate resistance to change in the first phase of their transformation model, followed by a second phase (creating and maintaining a new pathway), and a third phase (mainstreaming the new pathway and replacing the existing unsustainable regime). The 2024 *Nature Sustainability* editorial [7] also presents resistance as something that needs to be overcome in the early phase of transitions, preceding the acceleration of socio-technical change.

We criticise this understanding of resistance as too simplistic because it insufficiently acknowledges the multi-dimensionality and temporality of socio-technical transitions and actor strategies [28]. Instead of viewing resistance as limited to a particular *phase* of transitions, our novel contribution to the literature is to reframe resistance as a persistent *dimension* of transitions that is present in multiple phases and changes over time in terms of focus and type of strategy. To conceptualise the temporal evolution of resistance strategies, and thus understand the industry playbook, we adopt a five-phase model of strategic reorientation by incumbent firms and conceptually extend this by situating the various resistance strategies in the different phases. Our novel perspective also recognises that incumbent firms can resist in some dimensions (e.g. against particular policies), while simultaneously engaging in low-carbon reorientation in other dimensions.

We illustrate and refine this perspective with a comparative case study of incumbent automakers in the US, Germany, and Japan. Our findings reveal that, while these incumbent automakers are presently investing in electric vehicle models, battery plants, and new supply chains, their resistance continues. This is particularly visible in their efforts to dilute climate policies and EV sales targets and their requests for protection through tariff barriers or support through grants. This implies that incumbent firms' strategies are not necessarily congruent and may have varying orientations in different dimensions or strategic arenas. Metaphorically, incumbent firms are thus playing 'multi-dimensional chess' during which resistance strategies evolve throughout the game.

The paper is structured as follows. Section 2 presents our conceptual framework, which extends an existing model of incumbent firm reorientation by positioning various resistance strategies in different phases. Section 3 discusses our research design. It explains in more detail why we selected incumbent automakers in three different countries (US, Germany, and Japan) as our comparative case study. It also discusses data sources and the pattern-matching methodology we use for data analysis. Section 4 presents the three longitudinal case studies, focusing on contextual pressures and resistance strategies along with innovation and economic positioning strategies. Section 5 uses pattern-matching to compare the empirical cases with the ideal-type conceptual model. Section 6 concludes.

2. Conceptual framework

To conceptualise the temporal evolution of resistance strategies of incumbent firms, we draw on and extend the five-phase model of low-carbon reorientation, originally proposed by Penna and Geels [29,30]. This model was developed out of the Triple Embeddedness Framework (TEF), which conceptualises the various pressures on incumbent industry actors (from customers, suppliers, wider publics, NGOs, policymakers) along with their response strategies (including economic positioning, innovation, framing, and corporate political strategies) [31]. Incumbent firms normally focus on incremental changes in technology, products and markets, because they are locked into existing industry regimes. More radical change and strategic reorientation, including in low-carbon directions, therefore requires increasing external pressures from economic and socio-political environments to 'unlock' incumbent firms from existing industry regimes and stimulate their shift to new technologies, beliefs and operational templates [29,30].

The TEF-based five-phase low-carbon reorientation model (hereafter the five-phase reorientation model) posits that external pressures on firms gradually increase through five phases. In phase 1, pressures tend to come from scientists, disadvantaged citizens, or civil society activists. In phase 2, these spill over to the media and public debates, creating pressures on policymakers to first debate the problem, and then in phase 3 to introduce substantive policies. Phase 4 is characterised by the emergence of small market niches, which generate *economic* reorientation pressures. In phase 5, economic pressures increase as market demand significantly grows.

The five-phase reorientation model also distinguishes five strategies with which firms respond to the increasing pressures in successive phases: 1) disregard of the problem and lack of substantive action; 2) acknowledgement of the problem and incremental change to address it; 3) hedging, which involves both continuation of incremental changes and some effort to explore more radical alternatives [32]; 4) diversification, which involves more significant engagement in the production and selling of radical alternatives, while 'milking' the old technology; and 5) full reorientation, when firms comprehensively shift to new technologies and often also change mission, identity and mindset.

Several studies of low-carbon reorientation have applied the five-phase reorientation model, examining the US car industry 1979–2011 [29], German electricity industry [33], UK petrochemical industry [34], UK steel industry [35] and UK oil refining industry [36]. Richter and Smith Stegen [19] also used it to analyse the German car industry's strategies in response to environmental policy initiatives.

While these studies confirmed the general usefulness of the ideal-type five-phase reorientation model, scholars also found that real-world cases do not necessarily unfold in a linear fashion [19,29,30]. They therefore amended the model by acknowledging that incumbent firm reorientation may move backwards to earlier phases (or stagnate in a particular phase) when external pressures (from policymakers, civil society, or markets) weaken and when incumbent firms successfully resist external pressures or revert to earlier strategic positions (or do not reorient to the next phase). These studies also found that external pressures in socio-political and economic environments may wax and wane asynchronously, giving rise to more complex response patterns, which may advance in one dimension, but reverse in another [19,30].

To conceptualise the temporal evolution of resistance strategies, this paper extends the five-phase reorientation model by positioning the various resistance strategies, discussed in section 1, into each phase of incumbent firm reorientation. In the first stage, when the climate change problem is emerging and being articulated, we expect that firms either ignore it or use *information strategies* that deny or question the problem or present alternative facts or theories [2,18,20].

In the second stage, when the problem becomes difficult to deny, incumbent firms begin to defend themselves against public and media criticisms using *framing strategies* that portray critics as uninformed, irrational or hysterical [21,37], present other problems as more urgent, or emphasise that uncertainties are too large to warrant action. Firms may also create associations and form 'closed industry fronts' [29,30], using *organised pressure strategies* to protect collective interests of the entire industry [38,39]. For reputational and credibility reasons, firms may also allocate some R&D resources towards incremental innovations to create the impression of substantively responding and to downplay the need for policies because of 'voluntary' technology development [40].

In the third stage, when policies are discussed and introduced, firms are likely to adjust their *framing strategies* to argue that policies or substantive technical solutions are unfeasible, too expensive, unnecessary, or commercially disadvantageous [19]). Additionally, they will likely use politically oriented resistance strategies like lobbying, litigation, financial incentives, and participation in rulemaking to hamper and weaken policies. Yet, while publicly resisting, firms may privately start preparing for future transitions with *innovation strategies* that explore more radical alternatives, for which they may ask policymakers for financial support.

In the fourth stage, when public debates and policies affect the economic environment and stimulate growing market niches, incumbent firms are likely to increase their radical *innovation strategies* while strengthening their *economic positioning strategies* through investments in manufacturing, supply chains, and marketing [41]. Simultaneously, however, firms may continue to use *framing strategies* and various *political resistance strategies*, arguing that the speed of change is too high, that political targets are too demanding, and that low-carbon reorientation activities damage their competitiveness. They may additionally seek more financial assistance for building new factories or other forms of protection and support [42]. Although most firms in this stage accept the overall direction of travel, they will likely seize every contextual opportunity (e.g. temporary market slackening, supply chain problems, or cost increases) to push for more support, weakened targets, and delayed policy introductions – because every year of postponement saves expenditures.

In the fifth stage, when firms have fully reoriented, resistance strategies will subside because firms have shifted to a new regime, which they will aim to optimise and elaborate.

Table 1 summarises the relative prominence of the expected resistance strategies across different phases of incumbent firm reorientation. This ideal-type model conceptualises resistance as a persisting dimension that is present in four of the five phases. It also understands resistance strategies as temporally dynamic, evolving over time in terms of focus and type. This conceptualisation also underscores that resistance does not necessarily imply that firms are not reorienting. Especially in the third and fourth stage, firms can simultaneously reorient and resist with the aim of advancing their multi-dimensional interests.

Building on the earlier discussion of non-linearity, it should not be assumed that empirical cases of incumbent firm resistance and reorientation linearly progress through the five phases. In fact, the goal of incumbent firm resistance strategies is to delay, stop or even revert this progression. If external pressures weaken, for example because of policy reversals or shrinking market demand, incumbent firms may succeed in this goal. This can then lead to more complex temporal patterns of resistance and reorientation, including back-and-forth movements between phases, depending on the interplay of external pressures and firm response strategies.

Table 1
Ideal-type model of the temporal evolution of incumbent resistance strategies across different phases of low-carbon reorientation.

Phase	Resistance strategies
1. Inaction	Information strategy (e.g. deny the problem, attack science, highlight uncertainties)
2. Incremental innovation	a) Framing strategies (e.g. claim that a problem is not so bad or can be addressed incrementally) b) Organised pressure strategies (e.g. create a 'closed industry front')
3. Hedging	a) Framing strategies (e.g. claim that policies are not needed, radical solutions are too expensive), b) Lobbying strategies to prevent/shape legislation c) Confrontational strategies (e.g. litigate against policies) d) Innovation strategies (including radical)
4. Diversification	a) Innovation strategies b) Economic positioning strategies (e.g. invest in factories, products) c) Framing strategies (e.g. claim that the speed and cost of change is too high) d) Lobbying (e.g. to weaken targets and ask for policy support)
5. Full reorientation	a) Innovation strategies b) Economic positioning strategies

3. Research design

3.1. Case selection

We illustrate, test, and nuance this ideal-type conceptual model with three longitudinal case studies of incumbent automakers. We selected the automotive industry due to its high relevance for climate mitigation, and because the industry has recently begun to mass-produce electric vehicles, after years of resistance. We focus on the US, German, and Japanese passenger car industries, as these have a long history of ICE manufacturing and, during the case study period, were the biggest *incumbent* producers globally, holding significant economic importance in terms of GDP contribution, export value and jobs (Table 2). We did not select China because it did not have a significant incumbent automotive industry during the entire case study period. Indeed, a number of China's recent market entrants either never produced ICEs or have a short history of ICE production, meaning many did not have to undergo a transition from ICEs to EVs.

After years of resistance, automakers in all three countries have started to significantly reorient towards battery electric vehicles (BEVs). Yet each country's transition speed differs significantly, illustrated by domestic sales of BEVs (Fig. 1). Japan lags the transition, with new BEV sales reaching only 3 % in 2024. This reflects its early commitment to hybrid electric vehicles (HEVs), which now constitute the majority of domestic passenger car sales. Germany, contrastingly, shows rapidly increasing BEV sales shares, from 3 % in 2019 to 31 % in 2022. However, sales fell to 24 % in 2023 and 19 % in 2024, after subsidies were halted by a court decision. The US trajectory, with BEVs making up 10 % of new car sales in 2024, lies between Germany and Japan, with domestic firms increasingly focused on difficult-to-electrify light trucks. China's BEV sales, meanwhile, continue to increase. Reaching 48 % of all car sales in 2024 (Fig. 1), China has become a formidable global influence because of the sheer scale and importance of its BEV market in terms of both consumption and production.

These domestic sales figures should be interpreted with some caution, because the car industry is global. This means that not all domestic car sales are produced by local automakers. In fact, there is significant car trade between Germany, Japan, and the US (Table 3). This trade is rather asymmetrical, however, as Germany and Japan export many more cars to the US than vice versa. This means that German and Japanese automakers, which are major exporters in both countries (Table 2), pay strategic attention to the US' car market and climate policies, as our case studies will also show. US automakers, in contrast, have become increasingly domestically oriented over the past two decades, as their global market share declined and they focused more on profitable light trucks and wagons. Japan and Germany also sell cars in

Table 2
Economic importance of automotive manufacturing in 2021/22 (constructed using data from [43–47].

	Number of passenger cars and light commercial vehicles produced	GDP contribution	Export value	Jobs (in industry)
US	9.2 million	3 %	$97 billion	923,000
Germany	3.7 million	5 %	$274 billion	783,000
Japan	7.3 million	2.9 %	$410 billion	867,000

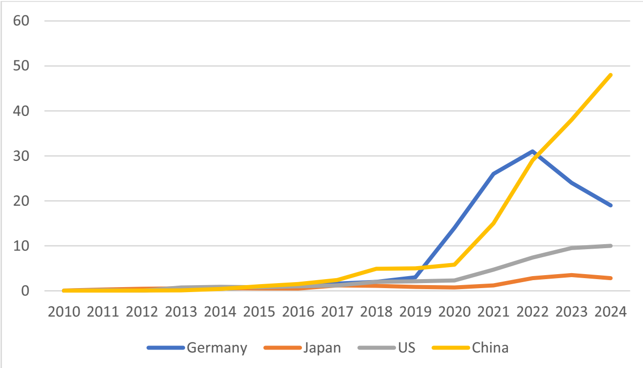

Fig. 1. Sales share (%) of BEVs in domestic car sales in Germany, Japan, the USA, and China (constructed using data from [48]).

Table 3
Trade value in 2024 (in billions $US) of motor cars and other passenger motor vehicles between Europe, Japan and the United States (data from [50]).

	Germany	Japan	United States
Germany exports to	0	$4,2	$27,2
Japan exports to:	$1,8	0	$39,6
United States exports to:	$7,9	$0,85	0

each other's markets, but the value of this trade is much lower than that with the US (Table 3). Japanese automakers do, however, keep an eye on European legislation, because their exports to Europe amounted to €12.3 billion in 2024 [49].

The analytical implication of this information is that the three case studies have a national and transnational dimension. This said, the transnational effect is larger for the German and Japanese cases than for the US case.

3.2. Data sources, data analysis and period demarcation

We collected qualitative and quantitative data from various primary sources (including company reports, association websites, government policy documents) and secondary sources (including academic studies, third-party reports, media coverage, and statistical datasets). We also draw on our experiences as advisors and contributing authors to the *International Expert Panel on Overcoming Resistance to enable Sustainability Transformation*, scheduled to report its findings to Nature Sustainability in 2025.

We integrated and triangulated the various data sources to develop longitudinal analytical narratives [51] for each case study that start with the emergence of the climate change problem in the 1970s and 1980s and trace core processes up to the present. Analytical narratives do not just describe longitudinal developments but "convert a historical narrative into an analytical causal explanation couched in explicitly theoretical forms" [52,p. 211]. The main theoretical concepts in our approach, which thus guide the case studies, are external pressures from the economic environment (including customers, suppliers, foreign competitors) and the socio-political environment (including wider publics, NGOs, policymakers) and strategic responses from incumbent firms. Using these concepts, we divided each longitudinal case study into different *empirical* periods, unique to each case, characterised by particular constellations of external pressure and endogenous response strategies.

For data-analysis, we then used 'pattern-matching', which is an established social science methodology that "compares an empirically based pattern with a predicted one" [53,p. 106]. Hall [54]) further describes it as follows: "The observations drawn from the cases are compared with the predictions from the theory to reach a judgement about the merits of the theory, on the basis of congruence between the predictions and the observations. This is a matter of judgment, rather than one of tallying points of congruence" (p. 28). Because of the paper's focus on temporal patterns, our pattern-matching application compares the *empirical* periods of the case studies with the *conceptual* phases of the ideal-type conceptual model to assess similarities and differences.

A possible risk in pattern-matching is 'confirmation bias', when researchers only select information that fits the model ('cherry picking'). To alleviate this interpretive risk, our pattern-matching analysis pays special attention to deviations between the empirical case studies and the ideal-type phase model. As long as such deviations can be explained with analytical categories from the conceptual model, they can be productive in terms of stimulating further analytical reflections.

To demarcate the empirical periods for each case study, we used a bottom-up approach. The periods consequently vary somewhat between the cases depending on country-specific external pressures and company response strategies. All three case studies start in the 1970s, because this is when the climate change problem first appeared as a scientific issue, resonating with phase 1 in our conceptual model.

For the US case study, we then used the following years as demarcations between periods: 1988 (when highly publicized Senate hearings raised climate change's political profile), 1997 (when the Kyto protocol further elevated political salience), 2003 (when automakers aborted their attempted EV reorientation and adopted hedging strategies), and 2016 (when automakers started to diversify towards BEVs despite increasing partisan political polarisation and policy alteration with Trump-1 weakening policy support, Biden strengthening it, and Trump-2 weakening it).

For the German case study, we used the following years to demarcate second, third, fourth and fifth periods: 1983 (when the Green Party's parliamentary election raised the political profile of green issues), 1995 (when an auto summit led to industry-political agreements for attaining more environmentally sustainable cars), 2007 (when policy and competitive pressures significantly increased), 2015 (when the Dieselgate scandal changed political, socio-cultural, and corporate dynamics).

For the Japanese case study, we used the following demarcations: 1990 (when California's Zero Emission Mandate, introduced in the same year, affected Japanese automaker strategies), 1997 (when Toyota commercially launched the Prius HEV), 2009 (when two smaller Japanese automakers launched mass-market BEVs, triggering explicit resistance strategies from Toyota and industry groups), and 2022 (when Toyota followed by Honda reluctantly accepted the need for BEV reorientation).

For each case study, the empirical analysis in section 4 provides an analytical narrative that describes each period in terms of the most salient external pressures and the main industry response strategies. Section 5 then performs a pattern-matching analysis that compares the empirical periods from the three case studies with the conceptual phases from the ideal-type model.

4. Case studies of evolving resistance strategies from US, German, and Japanese automakers

Period 1 (1970–1988): Early climate science and corporate inaction in all three countries.

External pressures: In the 1970s, climate change emerged as a research topic at scientific meetings and conferences where its possible causes and effects were debated [55]. Although environmental NGOs began calling for countermeasures, public attention remained low compared to other issues such as acid rain and the ozone hole [56]. Policymakers were also more concerned about energy security due to the first (1973) and second (1979) oil crises.

Industry response strategies: Because external pressures were limited in this first period, automakers in US, Germany, and Japan were unconcerned about climate change and took no significant action [57]. Some automakers like General Motors and Ford knew about climate change from internal research dating back to the 1970s but largely suppressed this information [58]. In the 1970s and 1980s, US, German, and Japanese automakers also dedicated some R&D to exploring non-fossil fuel options like batteries and fuel cells. Yet efforts were limited, mostly aiming to learn about research frontiers rather than developing these alternatives [59–61].

4.1. US automakers (1988–2025)

4.1.1. Period 2 (1988–1997): Denial and contestation

External pressures: In the second period, external pressures came from science, public attention and policymakers. General scientific pressure, which also affected the German and Japanese cases, increased significantly with the creation in 1988 of the *Intergovernmental Panel on Climate Change* (IPCC), which published comprehensive assessment reports (in 1990 and 1996) that galvanized public attention to the problem [55]. A very hot summer and the 1988 Senate hearings also elevated climate change to a political issue at the US federal level. The creation of the *United Nations Framework Convention on Climate Change* (UNFCCC) in 1992 also created a new platform for international climate policy negotiations. More directly influential for US (and Japanese) automakers, however, was California's Zero-Emission Vehicles (ZEV) mandate. Initially introduced in 1990 to address the urban petrochemical smog problem, this subsequently became an important climate policy tool, requiring automakers to sell ZEVs in California, increasing from 2 % of fleet sales in 1998 to 10 % in 2003. In 1993, policymakers and automakers also created the *Partnership for a New Generation of Vehicles* (PNGV), aimed at developing a production prototype with a threefold improvement in fuel economy [62].

Industry response strategies: In response to these pressures, US automakers adopted denial and contestation strategies. Although GM and Ford were aware of climate change concerns from internal research, they largely suppressed this information, adopting instead a stance during the 1990s of questioning the certainty behind climate change science [58]. Using organised pressure and information strategies, both firms joined the Global Climate Coalition (GCC), which attacked global warming science and emphasised uncertainties from 1989 to 2001 [29]. Automakers also funded lobby groups and conservative think tanks that promulgated scientific misinformation. Ford, for example, donated more than $1.1 million to the American Enterprise Institute between 1985 and 1997 [58].

Automakers also used confrontational strategies like litigation, leveraging the legal system to challenge the authority of agencies to impose new regulations [63] such as California's ZEV regulations throughout the 1990s [24].

Despite the various resistance strategies, automakers also increased their innovation strategies. Most efforts focused on incremental improvements of existing Internal Combustion Engines (ICE) (e.g. direct fuel injection, lean burn), but the PNGV (1993–2001) also stimulated exploration of lithium-ion batteries, hydrogen fuel cells, and lightweight materials [64]. Automakers also used the PNGV to argue that voluntary action and public-private partnerships were more effective than 'command-and-control' regulations. Overall, however, the PNGV produced "few tangible results" [65] and lacked transformative outcomes [66].

4.1.2. Period 3 (1997–2003): Tentative but failed reorientation

External pressures: Although the US did not ratify the 1997 Kyoto Protocol, this treaty increased the political and societal prominence of climate change. External pressure on US automakers in this third period also came from foreign competitors, especially Toyota and Honda, which commercially launched HEVs in Japan (in 1997) and the US (in 2000). US sales of Japanese-made HEVs increased rapidly in the 2000s (Fig. 2), intensifying competitive pressure on US automakers. Pressure from California's ZEV mandate continued but weakened in this period, because limited ZEV sales forced policymakers to make successive adjustments like postponing some requirements, establishing a credit system, and allowing partial ZEV vehicles (like HEVs) to count towards meeting requirements [67].

Industry response strategies: In response to these pressures, US automakers left lobbying groups that contested climate change science like the GCC for fear of damaging their reputation [59]. But automakers and their associations also continued confrontational strategies like litigation against the ZEV mandate, preferring a voluntary rather than mandated approach [68]. These strategies weakened the mandate's ZEV-forcing effect [24].

Regarding innovation strategies, US automakers used the PNGV to control and delay technical change [59], while also employing defensive framing strategies that emphasised the high social and economic cost of reorientating towards electrification. To suppress demand, they also underlined to consumers and regulators the limitations of early electric cars like their limited range, high price, and the absence of charging infrastructure [69].

Nevertheless, the ZEV mandate and PNGV also led automakers to allocate more resources to radical R&D [29], including to BEVs. In 1999, Ford acquired and integrated TH!NK, a Norwegian manufacturer of small electric cars, into a newly created 'mobility' division [70]. GM also launched their first and second generation EV1 between 1996 and 1999, though both GM and Ford backtracked on their market experimentation

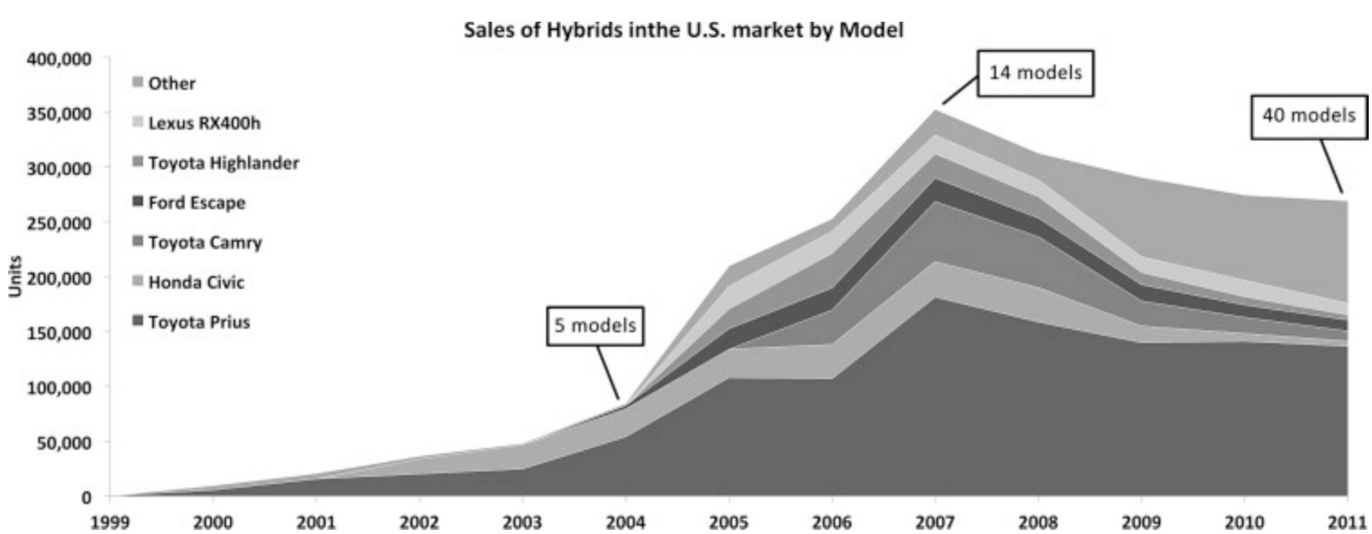

Fig. 2. HEV sales in the US market by model [29,p. 2041].

with BEVs. Ford sold TH!NK in 2003, as part of a wider consolidation strategy that reversed diversification efforts. GM famously recalled and destroyed almost all the EV-1 s in use in 2003.

Instead of reorientation towards electric drivetrains, US automakers shifted their climate-oriented R&D and economic positioning strategies towards 'flex-fuel' vehicles and corn-derived E85 (ethanol). This more incremental change enabled continued use of ICEs, while lowering CO_2 emissions. The percentage of E85 flex-fuel vehicles rapidly increased from 5.2 % of light-duty vehicle sales in 2003 to 14.7 % in 2011 [29]. Flex-fuel enthusiasm peaked around 2012–2016 as fuel efficiency regulations changed, and by 2024 just seven E85 models were offered on the market. This suggests that flex-fuel vehicles acted as intermediate options that delayed EV reorientation.

4.1.3. Period 4 (2003–2016): Hedging with multiple technologies

External pressures: In the fourth period, external pressures waxed and waned, pointing in different directions. Public attention to climate change first increased because of Hurricane Katrina (2005), Al Gore's movie *An Inconvenient Truth* (2007), the IPCC's 2007 *Fourth Assessment Report*, and the 2007 Nobel Peace Prize for Al Gore and the IPCC. But public attention decreased after the 2007/8 financial crisis. Although the Bush administration (2001–2009) generally weakened climate policies, it was concerned about rising oil prices in the mid-2000s, leading Bush to state in 2006 that 'America is addicted to oil'. To reduce oil dependence, subsequent policies aimed to increase biofuel use in cars, tighten fuel efficiency standards (CAFE), and launch the FreedomCAR & Fuel Partnership, founded with automakers and petroleum companies, which boosted R&D support for hydrogen [29].

The Obama administration (2009–2017) helped the industry by rescuing GM and Chrysler from bankruptcy following the financial crisis but also increased climate change-oriented pressures by reinforcing fuel economy policies [71]. Policymakers introduced the American Recovery and Reinvestment Act (2009), helping automakers with 'cash for clunkers' schemes and stimulating alternative technologies with consumer purchase tax credits for BEVs and Plug-in Hybrid Electric Vehicles (PHEVs). The Obama administration further reoriented electrification policies from hydrogen towards batteries, declaring in 2011 a target of 1 million EVs by 2015 backed with $5 billion in grants and loan guarantees for battery makers, automakers and equipment suppliers [72,73]. In 2012, new CAFE rules were announced for the period 2017–2025, prompting further efforts towards BEVs. Also in 2012, California's Air Resources Board adopted the Advanced Clean Cars program, mandating for at least 16 % ZEV sales by 2025 [74]. In 2015, the US signed the Paris Agreement to combat climate change.

External pressure on incumbent automakers also stemmed from markets, where consumers increasingly purchased biofuel/flex-fuel vehicles and (to a lesser degree) HEVs produced by competitors (Fig. 2). In parallel, BEVs and plug-in hybrids emerged, including the Tesla Roadster in 2008, the Nissan Leaf and Chevrolet (GM) Bolt in 2010, and plug-in hybrids from 2010. Tesla followed up with a series of models that both shaped the US BEV market and profoundly influenced the strategies of the US incumbent automakers. Tesla acquired the former NUMMI Toyota-GM joint venture plant in California in 2010, and started production of the Model S in 2012 and Model X in 2015. Though Tesla's annual sales in the US reached only 26,725 cars by 2016, it radically altered market perceptions, repositioning BEVs as high-performance, high-excitement cars with features such as 'ludicrous mode', twin-motor powertrain, and a proprietary high-speed charge point network of 'superchargers'.

Industry response strategies: In response to these multiple and varying pressures, incumbent automakers initially focused on opposing stricter CAFE regulations. They used framing strategies claiming that regulations would result in smaller, lighter vehicles that were less safe for occupants in the event of a collision [75]. They also used organised pressure strategies, orchestrating opposition through coalitions representing auto and oil firms, including the American Fuel and Petrochemical Manufacturers and the Alliance of Automobile Manufacturers.

Yet, while resisting politically, US automakers also shifted their economic positioning strategies further towards biofuel and flex-fuel vehicles, which they sold in increasing numbers until 2016. Additionally, they hedged their innovation strategies by increasing R&D efforts on alternative technologies, aided by federal support. Initially focused on HEVs [29], their R&D activities increasingly shifted towards BEVs, but without entering mass-production.

4.1.4. Period 5 (2016–2025): BEV reorientation and policy fluctuations

External pressures: In the fifth period, policy pressures fluctuated tremendously. They initially decreased, as the first Trump administration (2017–2021) withdrew from the Paris Agreement, dismantled many environmental regulations, and weakened the Environmental Protection Agency (EPA). The first Trump administration also reinforced doubts over climate change science and stimulated domestic oil production [76,77], thereby reducing ZEV-related pressures. These policy reversals exacerbated misalignments with European and Chinese markets, where policymakers further stimulated the transition to electrification, compelling US automakers to retain some EV development strategies. California, however, was able to retain its momentum, mobilising a coalition of vested BEV interests including automakers, electricity utilities, and charging network providers while retaining consumer incentives [78]. This reinforced the significance of California for US BEV sales. Tesla was a major beneficiary during this period. US sales surged from 50,067 in 2017 to 670,000 in 2023 alongside the introduction of the Model 3 in 2017 and Model Y in 2020. The Panasonic–Tesla joint venture 'Gigafactory' in Nevada started production in 2017 with over US $1 billion of aid and tax breaks. Moreover, Tesla was able to sell BEV credits to the incumbent legacy automakers while continuing to expand the Supercharger Network.

Climate-oriented policy pressures increased again during the Biden administration (2021–2025), which scheduled new CAFE targets for 2027 [63] and established a non-binding target for a 50 % share of BEVs in new vehicle sales by 2030 [79]. The Biden administration also introduced the US Bipartisan Infrastructure Law (2021) and Inflation Reduction Act (2022) that offered lavish subsidies for EV purchases and the construction of EV and battery plants by US and non-US automakers. These industrial policies were motivated by both climate and competitiveness concerns as US automakers trail in the global EV race. In January 2025, however, the second Trump administration stated it would revoke California's ability to set its own (often stricter) emission standards while signing executive orders that reversed many pro-BEV Biden policies.

Increasing external pressures also came from foreign markets, where the unfolding BEV transition changed vehicle demand patterns that US automakers struggled to meet. Market pressures also increased within the US, where consumer demand for BEVs significantly increased since 2016 despite Trump's policy reversals (Fig. 3). Reflecting this, in 2024 market shares of electric, hybrid (including full, mild and plug-in) and petrol were 11.4 %, 17.9 % and 70 % respectively [80].

Climate-oriented policy pressures weakened again as the second Trump administration, which started in January 2025, rapidly sought via Executive Orders and the 'One Big Beautiful Bill' in July 2025 to undermine BEV-promoting policies. This included both direct measures such as stopping the Biden policies under the Inflation Reduction Act, a symbolic act being the discontinuation of the $7500 BEV lease credit system in September 2025, and indirectly through curtailing the powers of the Environmental Protection Agency. While BEV sales grew strongly in 2025, much of this is attributable to consumers rushing to acquire cars and automakers clearing stocks before the support measures ended. Tesla sales also started to suffer in the US due to an aging product line-up, weak demand for the long-awaited Cybertruck, and emergence of anti-Tesla consumer sentiment against Elon Musk's extreme Libertarian views [82].

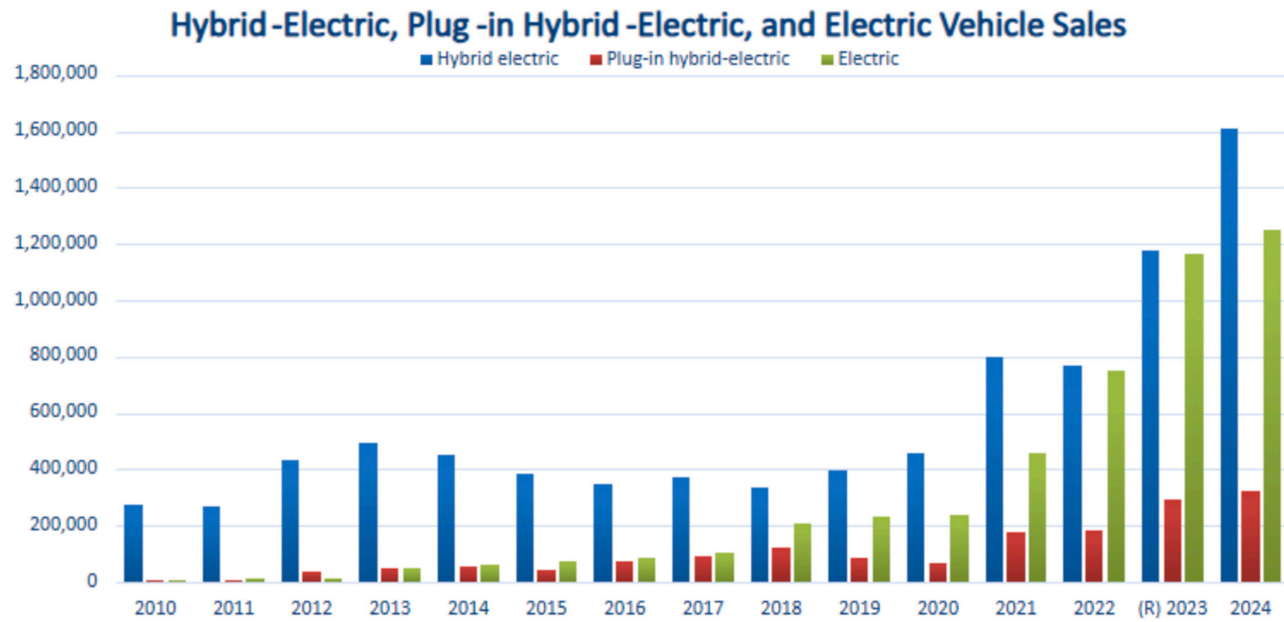

Fig. 3. Overview of US electric vehicle sales, 2000 to 2023 [81].

Industry response strategies: Despite policy reversals under Trump-1, US automakers began orienting more seriously towards BEVs since 2016. The Chevrolet Bolt (GM), Ford Fusion and Tesla vehicles sold in increasing numbers despite barriers such as the poor availability and promotion of BEVs at dealerships [83]. In 2017, Ford and GM announced major investments and targets for hybrids and BEVs, with GM aiming to supply 20 BEV models by 2023. Chrysler, however, never had a BEV-model in the market, despite selling various hybrid models. Biden's support policies such as the IRA further stimulated BEV reorientation. By 2024, claimed investments in BEV manufacturing in North America totalled $250 billion [84]. Although not responsible for all these investments, US automakers adjusted their innovation and economic positioning strategies as they made serious reorientation attempts, supported by Federal and State subsidies, as noted above.

Yet while reorienting towards BEVs, US automakers also continued to resist, with *retarding the pace of change* being the primary goal. For instance, the Alliance for Automotive Innovation along with user or consumer groups (e.g. Automobile Association of America (AAA) and Energy4US) have a long record of lobbying against BEVs [85]. The AAA also worked at State level, for example seeking to block rebates for electric vehicles in Oregon in 2019. In 2018, automakers also coordinated resistance strategies with conservative-learning entities (e.g. Koch Industries, Competitive Enterprise Institute, Americans for Prosperity) to prevent California from setting its own fuel-efficiency standards [85].

In parallel, automakers and their allies resisted Biden's mandates for BEV-adoption. For example, the Alliance for Automotive Innovation (claiming to represent 42 automakers supplying 97 % of the US market) issued a statement in 2023 against the proposed EPA regulations, claiming they would increase costs, reduce consumer choice, be unfeasible in the time allowed, and "disadvantage major portions of the United States populations and territory" [86]. Well-resourced pro-petroleum lobby groups also used large-scale advertising campaigns to influence public opinion and frame public debates [63]. US oil companies also blamed 'the market' (i.e. consumers) for demanding the wrong sort of car (i.e. ICEs) and claimed that automakers were simply responding to market demand [87]. The United Auto Workers (UAW) union lobbied for more time to implement the more stringent CAFE rules. Using information strategies, quasi-independent research groups such as the Center for Automotive Research (CAR) and the Institute for Energy Research also provided forecasts on job losses from car electrification and argued that the US should utilise its abundant fossil fuel resources to provide cheap petrol.

In response to the recent Trump-2 policy reversals, US incumbent automakers are slowing down their BEV diversification strategies but are not (yet) abandoning them. They are downscaling or delaying (but not scrapping) their multi-billion dollar investments in new BEV plants [88,89], and cancelling or postponing the launch of new BEV models, including the Dodge RAM electric pickup, Dodge Charger BEV, and Ford's full-size electric pickup and *E*-Transit. An important reason for these delays is that US market demand may decrease, as Ford's CEO Jim Farley said on 30th September 2025: "I wouldn't be surprised if the EV sales in this country go down to 5 percent of our industry" [90]. An important reason for not abandoning BEV diversification strategies is that global BEV markets are likely to continue to grow and that BEV costs will likely continue to decrease, meaning that US automakers will, at some point in the future, face foreign BEV competition within US markets.

4.2. German automakers (1983–2025)

4.2.1. Period 2 (1983–1995): Voluntary commitments in response to initial climate pressure

External pressures: In the second period in Germany, climate change emerged as a prominent socio-political issue in the 1980s, emblemised by the Green Party's 1983 parliamentary debut. In 1988 and 1990, the government released its first climate mitigation reports, which focussed on the power-generation industry [91]. At this juncture, the government was not targeting the automobile industry—which comprises the Volkswagen Group, the BMW Group, and the Mercedes-Benz Group (formerly DaimlerChrysler, 1998–2007, and Daimler, 2007–2022)—and in 1990 the automakers were allowed to submit voluntary emission reduction pledges [92,93]. However, the German automotive industry felt some pressure in 1990 from California's ZEV mandate, because of the significance of the Californian market for German cars.

A few years later, the German Environmental Ministry called for more efficient cars and, in 1993, Greenpeace Germany produced a three-litre engine prototype, which pushed policy discussions towards industry-wide adoption of these more environmentally friendly vehicles. These discussions culminated in a 1995 auto summit, where the government agreed to eschew environmental taxes and speed limits, expand road construction, and provide tax reductions for diesel cars in exchange for voluntary commitments by the automakers to manufacture three-litre vehicles by 2000 and to not dismiss employees [92].

Industry response strategies: With limited government pressure in these early years, automakers (other than the so-called 'three-litre vehicle' pledge) largely maintained a business-as-usual approach. They mostly focused on incremental innovation to improve their high-performance ICEs, but also experimented somewhat with radical innovations, influenced by policy developments in the United States. Being tech-savvy, German carmakers historically had made forays into exploring non-fossil fuel options, often supported by German government funding. Because Germany's battery industry and expertise had shifted to Asia in the 1970s, early research primarily focused on fuel cells and hydrogen. After California's 1990 ZEV announcement, however, interest expanded to other technologies like batteries [94].

Automakers also used organised pressure strategies to resist climate policies. Germany's main automobile lobbyist, the Verband der Automobilindustrie (VDA) lobbied against emission targets and EVs and used framing strategies suggesting that policies should stay "technologically neutral/open" [95,p. 814]. Automakers also used lobbying strategies, such as the private meetings with political elites that led to the 1995 auto summit deal [92].

4.2.2. Period 3 (1995–2007): Hedging strategies in response to climate policies

External pressures: In the third period, policy pressures increased as transport CO_2 emission and fleet efficiency quotas entered political discussions. In 2000, the German government included transportation emission reductions in a multi-sector policy package, prompting automakers to again submit voluntary pledges [91,96]. Meanwhile, the rollout of three-litre vehicles stalled due to economic positioning strategies that priced these vehicles higher than their less efficient counterparts [97]. Competitive pressures also increased in this period following the launch and diffusion of Toyota's Prius HEV.

Industry response strategies: In response to these pressures, German automakers started hedging their innovation strategies. BMW, DaimlerChrysler, and Volkswagen pursued incremental changes, for example, by furthering research into diesel and making minor improvements to ICEs. Simultaneously, the carmakers increased their radical innovation work on alternative drive trains, with DaimlerChrysler, for example, developing a Smart EV. The companies also engaged in framing strategies, asserting that more sustainable models were just around the corner, such as DaimlerChrysler's 1999 projections that it would commercialise Fuel Cell Electric Vehicles (FCEVs) by 2004 and quickly ramp up to 100,000 (which never materialized) [98]. In the early 2000s, German automakers refined their innovation strategies, shifting their focus to HEVs and PHEVs, which would allow them to offer ICE performance and driving range while touting sustainability advantages [99].

By the early 2000s, German automakers had gained research capabilities in alternative powertrains, especially with fuel cells and hydrogen. But few alternative propulsion vehicles made it to the roads. Amidst uncertainty about the optimal path forward, automakers remained uncommitted, perceiving all alternatives as less attractive than high-performance ICE vehicles because of higher costs, diminished driving range, and underdeveloped charging infrastructure [100–102].

4.2.3. Period 4 (2007–2015): Further hedging while policy pressures ramp up

External pressures: The fourth period saw continued competitive pressure from Japanese HEVs, especially from Toyota's Prius, which experienced significant market success in the US, Japan, and Europe.

Policy pressures also substantially increased in this period, from both Berlin and the European Union (EU), the latter setting pollutant limits and emission standards for all Member States. In 2007, the European Commission (EC) began drafting emission standards for passenger cars that would particularly affect German manufacturers because of their larger and more emission-intensive engines. In a coordinated lobbying strategy, the German industry and lobbyists worked with politicians in both German and EU positions to shape European policy debates, succeeding in weakening the EU's vehicle emission standards when they were released in 2009 [103].

Although the German government fought to protect its automotive industry at the EU level, it recognised the need to push non-ICE options. In the late 2000s, the government therefore launched a National Plan for Electric Mobility that supported battery R&D and set a goal of reaching one million on-road EVs by 2020 [104,105]. Policy pressure further increased with the EC's 2011 Transport White Paper, which called for stricter emission standards and accelerated EV diffusion. In 2012 the EU started discussing legislation to slash vehicle emissions, which led to Germany's Chancellor engaging in high-level lobbying by personally calling the EU President to persuade him to delay voting. Using threats to close auto plants in EU Member States (MS) and promises to cooperate on other issues, Germany then lobbied its way to a plan with more favourable terms for its auto industry [93]. Additional important EU pressures from this period include a 2014 requirement for developing alternative mobility infrastructure and a 2014 tightening of CO_2 emission targets.

Industry response strategies: German automakers resisted EU policy initiatives by using organised pressure strategies, such as lobbying via the German 'trifecta' of industry, lobbyists, and politicians. These three groups had long had 'chummy' relationships and 'revolving doors of employment' [95,106]. As described above, this lobbying against stricter EU policies played out both at bureaucratic and top political levels. Representatives of the auto industry also publicly decried the EV push and pursued framing strategies that questioned battery durability (Volkswagen) and underscored high costs (Daimler) [107].

Although the German automakers resisted change in some dimensions, increasing policy pressure galvanized them, and their innovation and economic positioning strategies began to move from hedging towards tentative diversification. They continued making incremental ICE innovations, particularly for diesel engines, but also increased their radical innovation efforts by further investing in EVs and successfully launching several electric and hybrid models. Daimler, for example, released Smart EV prototypes. Meanwhile, BMW and Daimler installed new CEOs who both emphasised future technologies and explored strategic alliances, such as Daimler's 2009 purchase of Tesla shares. Volkswagen introduced smaller, more efficient ICE vehicles and experimented with biofuels. Despite these activities, however, overall progress remained slow, in terms of both sales and industry commitment.

4.2.4. Period 5 (2015–2025): Electric vehicle diversification in rapidly changing political and economic contexts

External pressures: The fifth period was ushered in by the 2015 Dieselgate scandal, when Volkswagen was caught manipulating diesel emission tests in the United States. This crisis tarnished the entire German car industry's reputation, with some observers suggesting that German policymakers were also complicit [108]. The social and political outrage led the government, in 2016, to introduce subsidies and tax breaks for EV purchases, and the Federal Minister of the Interior even suggested that fossil-fuel cars should be banned by 2035.

After the Dieselgate crisis, the German government became more engaged in helping the EU forge emission standards [95]. In the late 2010s, the EU's sustainability-oriented legislation continued apace with regular new announcements, including the 2019 European Green Deal and the introduction of stiff fines for companies missing the 2020/21 CO_2 emission targets. For the automotive industry, however, the most significant pieces of legislation were the Euro 7 emission standards and the EU's ZEV mandate, which called for steep emission reduction targets for cars (55 %) and vans (50 %) by 2030, and a ZEV requirement for all new cars after 2035 [109].

Economic pressures also rose in this period, particularly because of surging BEV production and demand in China (Fig. 1), which had become the world's largest car market. China's heightened supply and demand were the result of generous policy incentives to manufacturers and consumers. The effects were threefold: Chinese BEVs made inroads in EU markets and opened showrooms in key cities; China's EV-focussed car companies started exporting affordable and increasingly high-quality BEVs to other parts of the world, where they competed with incumbent automakers, including from Germany; and EU manufacturers faced greater domestic competition in China. In October 2025, several German automakers reported sales' downturns in China, with Chinese consumers preferring local and less expensive EVs [110]. In response to Chinese automakers' penetration of EU markets, in mid-2025 the EU implemented tariffs on Chinese EVs imports, which Chinese automakers plan to circumvent by starting production in the EU.

Competitive pressure in this time period also came from the rising popularity of other non-German rivals, such as Tesla, as well as from heightened demand for BEVs globally.

Industry response strategies: In response to these pressures, German automakers initially adjusted their economic positioning strategies towards building and selling more electric vehicles. After the Dieselgate crisis, Volkswagen announced plans to invest more than €20 billion in e-mobility by 2030 [111]. Other manufacturers also released ambitious EV plans. Daimler promised to become fully electric by 2030 (a promise it is re-considering), and BMW expanded its EV lineup [112,113].

Despite the reorientation efforts, the German trifecta simultaneously implemented myriad resistance tactics to delay losing its ICE cash cow. In 2017, when European ZEV discussions began, VDA's President, a former German politician, lobbied other German politicians (including some with EU positions) against ZEV quotas, securing their temporary dismissal [103]. In subsequent years, the German trifecta made a 'full-court press' to have ICEs running on 'climate neutral' e-fuels allowed past 2035. This opposition was exemplified by BMW's CEO in 2024, when he called the ZEV requirement 'naïve', warned of job losses, and ventured towards an information strategy by contesting the scientific definition of 'ZEV's. Faced with steady and strong resistance from all sides of the trifecta, the EU buckled and e-fuel ICE vehicles are now recognised in the ZEV 2035 mandate [95; 114; 115].

In late 2024, Volkswagen stunningly announced it was in a deep crisis and would undertake drastic cost-cutting measures. The CEO mentioned the pressures exerted by new competitors, while an employee representative blamed Volkswagen's management for not producing cost-effective EVs in time to meet the competition. As before, the German government is rallying to support its industry, with a 2025 proposal for a €30 billion 'Resilience Fund' for clean technology sectors, including the auto industry—which engaged in heavy lobbying while the Fund was being discussed.

In 2025, the European ZEV mandate was again in the trifecta's crosshairs. After high-level talks between German political and auto industry leaders, Germany again challenged the ZEV 2035 requirement and attempt to persuade other auto-manufacturing EU MSs to join its efforts. In opposition, 150 EV-related companies published an open letter to the EU urging it to stick with the 2035 ZEV goal [110]. The German auto industry also contested the EU's Euro 7 emission standards, with the VDA and other stakeholders framing them as unnecessary and costly distractions. Confronted with intense lobbying and organised pressure campaigns, which included other EU Member States, in 2025 the EU softened the standards.

The resistance efforts undertaken by German automakers indicate that, although the EV reorientation is underway, it is by no means complete or wholehearted. The German industry's slow progress is partly explained by its disadvantages vis-à-vis recent market entrants, like many of the new Chinese firms unburdened by legacy ICE assets. Germany's cars are relatively large and heavy, rendering electrification more costly. Its workforce includes hundreds of thousands of ICE-dedicated employees, and the industry depends on other countries for battery expertise. From the consumer side, charging infrastructure in Germany remains inadequate, and German electricity prices are among the highest in the world, eroding running cost advantages [116].

4.3. Japanese automakers (1990–2025)

4.3.1. Period 2 (1990–1997): Experimentation with diverse electrification pathways

External pressures: In the second period, external reorientation pressures on Japanese automakers were mostly political, chiefly stemming from US policies such as the 1990 ZEV-mandate in California and the 1993 federal Partnership for a New Generation of Vehicles (PNGV), a public-private R&D programme [117–119].

Industry response strategies: Responding to California's ZEV mandate, Japanese automakers lobbied to weaken the state's ZEV ambitions [120,121]. However, they did not contest climate science and broadly accepted the direction of travel (electrification). Consequently, they intensified their innovation efforts to develop electric drivetrains, including BEVs, HEVs and FCEVs [122]. This strategy reflected a common view across managers at Toyota, Honda and Nissan, who all relied strongly on the US market for exports, that ZEV-promotion policies provided a long-term opportunity to compete with overseas rivals through technology development [121,123]. Japanese automakers were confident in their electrification abilities, since they had accrued relevant knowledge from pre-1990 R&D programmes [61], and because Japanese industry was globally competitive in electronics, batteries and electrochemistry. Japanese automakers thus jumped to phase 3 in the conceptual model, increasing their radical innovation strategies, searching and hedging multiple options due to uncertainty about the optimal zero-emission pathway.

At Toyota, managers set an internal goal of developing a car with 100 % fuel economy improvement, prompting engineers to explore multiple options between 1993 and 1997 [59]. Toyota and other automakers initially considered BEVs as the most promising technology [120], releasing limited-production vehicles to trial several battery chemistries, including lead, lithium-ion and nickel metal hydrates. They also explored FCEVs, where Japanese firms led the world. But they increasingly focused on HEVs, which were closer to market than FCEVs, and suffered less from limitations faced by BEVs, like limited driving range (due to poor energy density), long charging times, and limited recharging infrastructure availability [117,124]. The focus on hybrids in innovation efforts culminated with the commercial launch of Toyota's Prius in 1997, coinciding with the ratification of the Kyoto Protocol [120]. This deliberate timing symbolically demonstrated how Japanese automakers perceived international climate policy as a business opportunity rather than a threat.

4.3.2. Period 3 (1997–2009): Accelerated reorientation to hybrids

External pressures: In the third period, external pressures mostly came from increasing market demand for HEVs, exceeding expectations in both Japan and the United States [66,122], where the Prius launched in 2000 to become the best-selling HEV throughout that decade (Fig. 2). In 1998, Honda, Toyota's main rival, launched their first HEV (Clarity). Recognising the potential of hybrids to further decarbonisation and Japan's technological competitiveness, the Japanese state enthusiastically promoted their production and sale by providing consumer subsidies and including hybrids in its prioritized clean vehicle development plans [118]. Another driving force came from adjustments in California's ZEV mandate, which in 1999 included HEVs as an option to meet increasing ZEV-sales targets [120].

Industry response strategies: Toyota management, who initially saw the Prius as an "experiment with only a 5% chance of success" [66,p. 28], was positively surprised by strong consumer demand within Japan and internationally. This stimulated Toyota, Honda and other Japanese automakers to increasingly reorient towards hybrids by enhancing their economic positioning strategies, thereby exhibiting elements of phase-4 in our conceptual model. Toyota and Honda aggressively invested in production facilities [124] while frequently releasing improved HEV models (e.g. Toyota Camry and Honda Civic) along with plug-in varieties [125]. They also competed to lower sales prices, further propelling HEV sales in Japan [122] and the US [29]. Honda, for example, positioned its Civic as the HEV "for everybody". By 2010, the share of hybrids in new vehicles sales in Japan reached 10 % [126]. Japanese automakers also dominated global HEV sales and patents, seizing 95 % of global HEV sales between 1997 and 2008 [122, Fig. 4].

Although Japanese automakers increasingly focused their economic positioning strategies on HEVs, they also continued to hedge their innovation strategies by developing other technologies such as FCEVs and BEVs, which Toyota and Honda saw as the two best *long-term* electrification pathways [127]. Toyota's interest in BEVs later declined, however, because it failed to develop reliable, long-range vehicles with nickel-metal hydrates, which was the shorter-range battery technology used for its hybrids [124]. Nissan and Mitsubishi, which mostly focused on BEVs, also hedged their innovation strategies, by including HEVs [120,122].

Despite these reorientation activities, all Japanese automakers continued to produce and sell ICEVs, which still constituted the bulk of sales and income. But while continuing to 'milk' traditional ICEV models and assets, they also reoriented towards alternative technical trajectories. Smaller companies (Nissan, Mitsubishi) focused on BEVs and bigger companies (Toyota and Honda) prioritized HEVs, with Toyota making substantial investments with Panasonic in nickel-metal hydride battery manufacturing plants. These dynamics subsequently came to dominate Japan's overall automotive trajectory.

Toyota and Honda also continued to use lobbying strategies to 'soften' rather than block ZEV policy, aiming to ensure selection environments were supportive of HEVs [24,121].

4.3.3. Period 4 (2009–2022): Resistance towards BEVs and defence of HEVs

External pressures: In the fourth period, external pressures pointed in multiple directions. Growing demand for HEVs in Japan and overseas markets stabilised and extended the HEV reorientation trajectory of dominant automakers (Toyota, Honda). But BEV-oriented pressures also increased, particularly from 2009 to 2010 onwards, when two smaller automakers (Mitsubishi, Nissan) successfully leapfrogged hybrids to launch the world's first mass-market BEVs: the i-MiEV and Leaf. Demonstrating the feasibility of BEVs as an electrification trajectory, these vehicles prompted domestic policymakers to strengthen support for BEVs. Measures included setting targets to install 37,000 rapid chargers by 2014 and boost adoption, aiming for a 50 % share of 'next-generation vehicles' in new sales by 2020 [118,128]. Meanwhile, pressures also escalated from foreign markets and producers. These included China, where policymakers stimulated production and adoption of BEVs since the early 2010s, leading to substantial growth after 2015 and a surge after 2020 (Fig. 1); the US, where demand for BEVs increased after 2016; and the G7, which advocated for ICEV phase-out [129].

Industry response strategies: In response to market demand and positive economic performance, Japanese automakers deepened their reorientation towards HEVs, reaching phase-4 in our conceptual model. But automakers like Honda and Toyota also continued to hedge their innovation strategies, which has phase-3 resonance, continuing their work on radical innovations like FCEVs and batteries.

With these BEV-oriented pressures threatening the HEV reorientation strategy, Toyota and other automakers mounted fierce resistance to BEVs throughout this period. Resistance strategies thus concerned the direction of travel and leveraged organised pressure, information, political pressure and framing strategies.

Toyota deployed organised pressure strategies by mobilising the Japan Automotive Manufacturers Association (JAMA) [130], whose industry-wide membership comprised other firms lagging in electrification (Mazda) or focused on hybrids (Honda). This (relatively) closed industry front coordinated and aligned other resistance strategies with Toyota, whose CEO chaired JAMA.

Timed to coincide with the BEV launches by Mitsubishi and Nissan, Toyota's and JAMA's anti-BEV information strategies started around 2009–10, targeting the public and policymakers through the media and company communication channels. Early strategies emphasised the limited technological capability and market potential of batteries [131,132]. Discourse sharply amplified after 2021, when the Japanese state announced a goal to achieve 100 % ZEV sales by 2035. Given that BEV technology advances in the late 2010s had eroded the plausibility of criticisms about driving range and charging times, Toyota switched to an environmental line of contestation, arguing that BEVs offer negligible CO_2 reductions over the entire lifecycle due to prevalent fossil-electricity use in recharging [130,133,134].

Toyota and JAMA also used framing strategies that emphasised the economic risks to firms and jobs from a BEV transition [61]. From 2020 to 2021, messaging on television, newspapers, press conference and websites warned of potential harm to 5.5 million people working in Japan's automotive sector if ICEVs were phased out in accord with the state target of 100 % ZEV sales by 2035 [133,135]. Toyota also raised fears of possible business model collapse at press and investor meetings [136] and openly opposed ICEV phase-out and BEV-focused policies [137]. To muster support for hybrids, hydrogen and e-fuels, Toyota and JAMA additionally crafted a discourse that the 'enemy is carbon', not the internal combustion engine [135,138].

Another framing strategy shared by Toyota [133], JAMA, and other

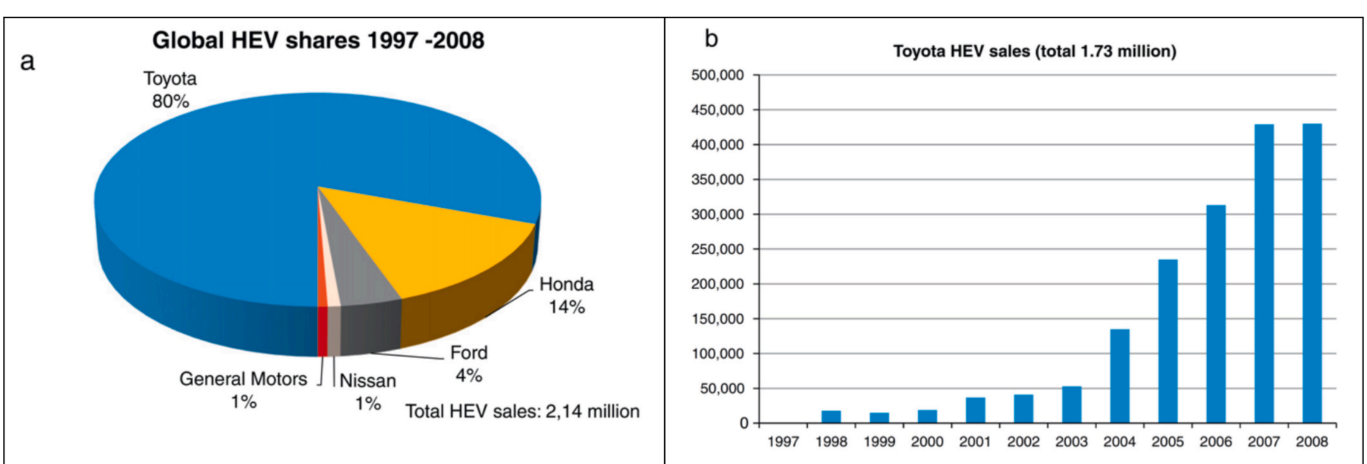

Fig. 4. HEV sales global and in the US market [119,p. 1432].

firms involved equating HEVs (both conventional and plug-in) with BEVs, labelling each as 'electrified vehicles' ('dendosha' in Japanese). The argument that HEVs deserve equal treatment with BEVs in government policy aimed to weaken the technology-forcing effect of ZEV promotion measures [139]. Meanwhile, Toyota, Nissan, Honda and Subaru all started to frame their hybrids as 'electric' in marketing messages, using labels like Hybrid EV, e-POWER, e:HEV and e-BOXER [140,141].

Multiple automakers, including Toyota's CEO, collaborated with JAMA to exert political pressuring and lobbying strategies, directly pushing policymakers to delay, weaken or prevent ZEV policies. These efforts not only targeted emission regulations [142] but also aimed to ensure recognition of hybrids in ZEV policies domestically [143], overseas, and by the G7 [129].

4.3.4. Period 5 (2022–2025): Serious but reluctant and slow diversification towards BEVs, while hedging

External pressures: In the fifth period, external pressures mostly stemmed from international markets. These included rising demand for BEVs in Europe, China and North America; declining demand for Japanese-made ICEVs across Asian markets, forcing firms like Nissan to close Chinese factories [144]; and the accelerated encroachment of specialised and technologically advanced BEV manufacturers like Tesla, BYD and other Chinese automakers, into domestic and foreign markets. These international pressures stirred significant concerns among Japanese policymakers and automakers about falling behind in the global BEV race [61,145]. Additionally, ZEV regulations in California, China and Europe are increasingly forcing Japanese automakers to accelerate BEV production. Additional pressure has come from international institutional investors who have criticised Japanese firms (especially Toyota) for their anti-BEV stance and lobbying activities [146].

Industry response strategies: In response to these pressures, Japanese automakers have reluctantly begun to shift towards BEVs. Hybrids, however, remain the near-term focus, with Toyota, Honda and other automakers continuing to hedge with multiple technologies including batteries, hydrogen, and e-fuels.

Explicit resistance strategies weakened in this period, shifting from contesting the direction of travel (BEVs) to efforts aimed at slowing the transition speed. Ongoing resistance strategies notably include political lobbying to maintain government support for hybrids amidst increasing competition from Chinese-made BEVs in key Asian markets. In 2025, for instance, Toyota's Chairman was reported to have personally met and pressured Thai politicians to promote hybrids in national ZEV policies [147].

Honda and Toyota signalled more serious reorientation towards batteries by announcing new economic positioning strategies aimed at significantly increasing BEV production. In late 2021, Toyota [148] stated the aim to offer 30 BEV models globally by 2030, targeting annual sales of 3.5 million units. Additionally, Toyota pledged to grow its global BEV sales to 1.5 million units by 2026, expanding 15-fold from 2023 levels [149]. In 2023, Honda [150] announced that it would produce exclusively BEVs or FCEVs by 2040 (thereby ceasing ICEV production).

Toyota, Honda and Nissan also reoriented innovation strategies by ramping up investments in next-generation battery technologies like solid-state and improved Li-ion, with mass-production anticipated by 2027–2028 [151]. Solid-state batteries, touted by some as 'a game changer' [145], promise considerably longer driving range (over 1000 km), shorter charging and improved safety. The focus on solid-state batteries aims to transform Japan from a laggard to an innovative leader in the global EV race, while simultaneously reducing reliance on Chinese-controlled Li-ion battery supply chains. Signalling this ambition, in late 2025 Toyota announced a battery-manufacturing collaboration with mining company Sumitomo, reiterating the plan to launch mass-market BEVs equipped with all-solid-state technology during 2027–2028 [152]. Meanwhile, Toyota, Honda and Nissan have strengthened investments in battery manufacturing on Japanese soil as well as key overseas markets including the US, UK and Europe.

Despite these BEV reorientation efforts, Japanese automakers are also constrained by their reliance on HEVs as their new cash cow. HEVs continue to diffuse in Japan, reaching 61 % of domestic light-duty vehicle sales by 2024 (Fig. 5). Conversely, EV sales (including BEVs, PHEVs and FCEVs) accounted for just 3.1 % of domestic sales in 2024, with roughly half imported from overseas makers. The stifled uptake can be attributed to the limited past investments in BEVs and large-scale battery production by Japan's automakers, constraining the supply of Japanese-produced BEVs available today; low consumer demand [153], with BEV sales *falling* by 30 % in 2024 [154]; and underdeveloped, technologically redundant public chargers, a legacy of the Japanese state's early but insufficient efforts to install BEV infrastructure [130].

Japanese automakers are also reluctant to abandon HEVs due to their high profitability, with demand growing strongly domestically (Fig. 5) and internationally [156]. Toyota, especially, has benefited from HEV success, reporting record annual profits of ¥4.94 trillion ($US 30.85 billion) in April 2024, the highest in Japanese corporate history, largely thanks to hybrids [157]. With Honda and Nissan also profiting from HEVs, commercial success has locked Japanese automakers into a hybrid-inclusive electrification pathway, reinforcing their determination to milk their cash-cow for as long as possible. Reflecting this, Toyota [158] even describes a strategy to position PHEVs as "practical battery EVs" in its integrated report, while Honda [159] states in its report the desire to maintain HEVs as "core products" throughout the electrification transition.

This HEV lock-in has left Japanese automakers trailing overseas rivals in BEV and battery development, making it difficult to quickly reorient towards BEVs and compete in the global BEV race.

In parallel, lingering uncertainty in US and European markets around the speed of BEV sales growth coupled with financial pains reported by overseas competitors with stronger battery-centric ambitions have tempered the momentum of Japan's automakers in advancing their own BEV transition. Toyota, in late 2024, scaled back its BEV-production ambitions for 2026 from 1.5 to 1 million units, citing lower-than-expected overseas demand and profitability [160], exemplified by VW's financial woes and factory closures. Similarly, Honda, revised its target of achieving a 30 % global EV sales ratio by 2030 to 20 %, attributing the adjustment to weakened consumer sentiment and "changes in regulations" [161].

International trends have thus strengthened the headwinds facing Japan's EV transition and reinforced the persisting tactic of cautiously reorienting while hedging. This tactic is evidenced in the continuing advocacy by Toyota, Honda and electrification-laggards like Mazda for a "multi-pathway" or "multi-solution" electrification strategy encompassing hybrids, batteries, hydrogen and combustion technologies.

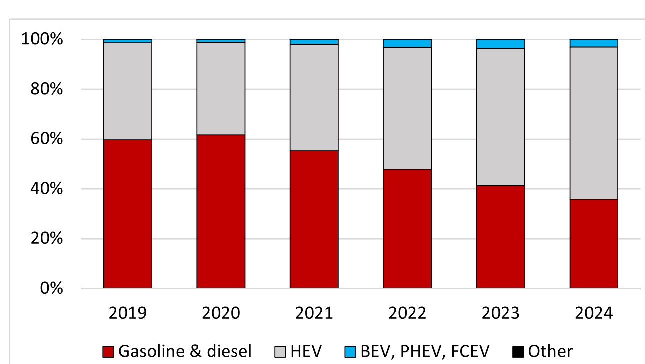

Fig. 5. Share of light-duty sales in Japan by drivetrain (constructed using data from [155]; data exclude vehicles in kei [light-duty] category).

Table 4
Ranking of relative prominence importance of five different resistance strategies as well as innovation and economic positioning strategies; absent or negligible = blank, low importance = +, medium importance = ++, high importance = +++.

	Information strategies (denial, contest the science)	Framing strategies	Lobbying strategies	Confrontational strategies (e.g. litigation)	Organised pressure strategies	Incremental innovation strategies	Radical innovation strategies	Economic positioning strategies
US								
1) 1970–1988	+						(small)	
2) 1988–1997	+++			+++	+++	+	+	
3) 1997–2003		++		+++	++	+ (E85)	+	+ (E85)
4) 2003–2016		++		+++	++	++ (E85)	++	++ (E85)
5) 2016–2025		++			++		+++	++ (BEV)
GERMANY								
1) 1970–1983							(small)	
2) 1983–1995		+	+		+	+	+	+
3) 1995–2007		+				+	++	
4) 2007–2015		+	+++			++	++	+
5) 2015–2025	+	++	+++				+++	++
JAPAN								
1) 1970–1990							(small)	
2) 1990–1997			+ (abroad)			+	+++	
3) 1997–2009			+ (abroad)				+++	++ (HEV)
4) 2009–2022	+	+++	+++		+++		++	+++ (HEV)
5) 2022–2025		++	+		+		+ (BEV)	++ (BEV)

5. Comparative analysis

The three case studies show that automakers in all three countries used multiple resistance strategies, which evolved over time and were *not* limited to the early empirical periods. This finding is clearly visible in Table 4, which summarises the prevalence of different resistance strategies in the five periods for each case, as well as automakers' degree of commitment to (incremental and radical) innovation strategies and economic positioning strategies, which are indicative of reorientation stages. All three cases show that automakers continued to use (some) resistance strategies up to and including the fifth period, when they embarked on serious BEV diversification strategies. This confirms the conceptual argument from section 2 that incumbent firms can simultaneously resist in some dimensions, while reorienting in others. In later phases, however, this resistance seems to be more about speed than about direction, given that every year of delay can save significant expenditure.

The case studies also show significant differences regarding the prevalent *types* of resistance strategies. US automakers used more overtly antagonistic strategies like contesting the science in the second period and litigation in the second, third and fourth period, both directly and via collective organisations (using organised pressure strategies). German and Japanese automakers were more inclined to use lobbying strategies, shaping policymaking through close consultation, revolving doors, and 'iron triangles' (where firms, politicians, and policymakers have close ties and identify with each other's interests). But they also used framing strategies and organised pressure strategies to shape policymaking debates and processes.

We argue that one reason for this difference is the variation in deeper state-industry relations. The varieties of capitalism literature [162–166] indicates that the US has a Liberal Market Economy, where the state has a limited role and coordination of activities occurs mainly via market competition. Our evidence supports the view that an adversarial interaction style with policymakers is more likely for US firms, where 'anti-government sentiment' is stronger [167]. For Coordinated Market Economies like Germany, where the state is more enabling and tends to have cooperative relationships with firms, and for State-influenced Market Economies like Japan, where the state plays a more active and interventionist role, our evidence suggests that firms develop more interactive, cooperative, and sometimes consensual relations with policymakers, who often tend to look after the interests of firms.

Another reason for differing strategies is the varying degree of ideological polarisation of climate change. In the US, polarisation is high and has increased over the past two decades [168,169], both in the population and in political parties, with Democrat administrations more likely to enact climate policies and Republican administrations more likely to weaken climate policies. This strong polarisation makes it more acceptable for firms to use information strategies (which contest or obfuscate climate change science) and confrontational strategies. In Germany and Japan, there is greater socio-political acceptance of climate change science, which makes climate science contestation or overt opposition potentially damaging for a company's reputation.

5.1. Pattern-matching analysis of low-carbon reorientation

A pattern-matching analysis between the five empirical periods and the five ideal-type phases of low-carbon reorientation, described in section 2, shows interesting differences and similarities between the three case studies. The first period, when climate change emerged as a scientific problem in the 1970s and 1980s, resonates well with the first conceptual phase because incumbent automakers in all three countries outwardly disregarded climate change (despite some conducting internal research on the problem) and took no substantive action (although they all pursued limited research into non-fossil fuel options).

The second period in each case matches the second ideal-type phase in the sense that external pressures increased as climate change rose on public and policy agendas and was more widely debated (linked to the creation of the IPCC and UNFCCC). But it also deviates from the ideal-type phase in the sense that US policymakers introduced strong substantive policies (like the California ZEV mandate and federal PNGV), which the ideal-type model expects in phase 3.

In terms of response strategies, the second period matches the ideal-type second phase because automakers in all three countries implemented incremental innovation strategies. But it also deviates, as automakers additionally implemented some radical innovation strategies (involving BEVs, HEVs, and FCEVs), which the conceptual model predicts for phase 3. The explanation for this deviation is that US policymakers introduced substantive policies in the second period, which led firms to increase exploration of radical innovations (also in Germany and Japan). A significant difference between the three case studies is that Japanese automakers, perceiving that low-carbon technological prowess could be an international competitive advantage, substantially increased their radical innovation strategies.

The third empirical period in each case matches quite well with the third conceptual phase as increasing public attention along with policy pressures led to hedging strategies from US and German automakers, who increased their exploration of radical alternatives (like BEVs, HEVs, and FCEVs) while continuing incremental enhancements of existing cars. One significant deviation is that Japanese automakers not only hedged their innovation strategies (exploring multiple alternatives) but also started producing and selling increasing numbers of HEVs, and incorporated this technology into their economic positioning strategies. This movement towards diversification, which the conceptual model predicts for phase 4, was due to the strategic interpretations and actions by dominant Japanese automakers (Toyota and Honda), mentioned above, and the presence of some market demand for low-carbon cars, which emerged earlier than the conceptual model predicts.

Another deviation is that US automakers started to incorporate biofuel and flex-fuel (E85) vehicles in their incremental innovation and economic positioning strategies, producing and selling more of these cars. The reason for this deviation is that electric drive policies weakened under the Bush administration (2001–2009) and that flex-fuel vehicles provided a pathway to maintain ICE-based production but reduce oil demand and GHG emissions.

The fourth empirical period resonates with the third conceptual phase for US and German automakers, who continued using hedging strategies that explored radical options (like BEVs and HEVs) but primarily focused on improving existing cars. The continued hedging in the US was due to variations in strength and direction of multiple external pressures, including a rise (2005–2008) and fall (post-financial crisis) of public attention to climate change, weakening policies (under Bush) and strengthening policies (under Obama). It was also due to the focus of US automakers on flex-fuel (E85) cars, which prolonged the reign of ICEs, and their reluctance to significantly reorient towards BEVs and HEVs. Continued hedging in Germany was also due to mixed external pressures, including a more assertive EU and significant push-back from German policymakers to protect their automakers, who preferred to stick with their traditional cash-cows rather than invest significant sums in EV reorientation. German policymakers did introduce some BEV-oriented policies, but these remained too weak to drive significant change.

In Japan, the fourth empirical period matches quite well with the fourth conceptual phase, because dominant automakers increasingly diversified towards HEVs, which was mostly a response to strong market pressures (driven by demand), both domestically and internationally. Smaller automakers (Mitsubishi, Nissan) also launched BEVs, but their market share remained small, despite some BEV-oriented public policies.

The fifth period resonates with the fourth conceptual phase in the US and Germany, because increasing pressures (from markets, Chinese competitors, and European ZEV regulations) stimulated US and German automakers to diversify towards BEVs, invest in battery and EV plants, and adapt their economic positioning strategies. Recent US policy reversals led US automakers to delay but not abandon their BEV diversification strategies. So, although reversal to earlier phases of strategic reorientation is theoretically possible, as discussed in section 2, we suggest that US automakers are still in phase four of the low-carbon reorientation process and have not reverted back to phase three.

In Japan, however, the fifth period is more complicated, with dominant automakers involved in a dual diversification process: while their orientation towards HEVs has advanced considerably, they are now also attempting to diversify towards BEVs. Japanese automakers are struggling with this dual diversification process because HEVs have become their new cash-cow, which they are reluctant to abandon, whereas BEVs have (unexpectedly) become the focus of a global innovation race, led by China. This means that Japanese automakers (and by extension the wider Japanese economy) may suffer if they do not catch up.

This pattern-matching analysis shows that the conceptual model is a useful heuristic for analysing low-carbon reorientation of incumbent firms, but also highlights that the ideal-type phases do not unfold linearly or deterministically. Although the case studies showed similarities, there were also significant variations depending on different external pressures in the three countries (which changed in size and directionality) and different strategies of automakers. These differences and the deviations between empirical periods and conceptual phases could, however, mostly be explained with categories from the triple embeddedness framework.

5.2. The evolution of resistance strategies during low-carbon reorientation

The resistance strategies of incumbent automakers did not follow a single temporal pattern, as indicated by the case studies and by Table 4. Instead, their temporal evolution shows interesting variation in terms of strength, focus, and types of strategies.

The US case most closely resembles the conceptual pattern described at the end of the section 2, although it also shows deviations. In the first empirical period (1970–1988), US automakers outwardly ignored the climate change problem but did not use resistance strategies. They did, however, marginally use information strategies because they suppressed findings from their internal climate change research. In the second period (1988–1997), resistance strategies were strong and focused on multiple dimensions (Table 4), with US automakers using information, confrontational, and organised pressure strategies to attack climate science and oppose policies. These overt and antagonistic resistance strategies were stronger than the second conceptual phase predicts, because US policymakers already introduced significant policies in the second period (e.g. California's ZEV mandate) that affected their vested interests. The third empirical period (1997–2003) resonates with the third conceptual phase, as US automakers weakened their information strategies (because science contestation became less tenable), but maintained strong litigation strategies and organised pressure strategies (although these softened somewhat as they left the GCC). They also increased the use of framing strategies to *oppose the direction* envisaged by policies, arguing that electric drivetrains were costlier and less functional than current cars. Resistance strategies in the fourth empirical period (2003–2016) were similar in strength and focus as in the third period, with automakers using framing, litigation, and organised pressure strategies to oppose EV-oriented policies. The main reason for phase-3 continuation is that EV market demand remained small (and smaller than flex-fuel vehicle demand). In the fifth empirical period (2016–2025), when automakers started to diversify towards BEVs, they continued to resist with framing and organised pressure strategies, but these now focused on *slowing the pace of change*. The strength of resistance also weakened in this period, as automakers dropped confrontational strategies like litigation, focusing instead on maximising receiving financial support for battery and EV factories, especially under the Biden administration. These strategic alterations resonate with the conceptual phase-4 predictions. The recent policy reversals of the second Trump administration resonate with the automaker's strategy to slow the pace of change, leading them to delay plant investments and cancel or postpone the launch of new BEV-models. They did not, however, abandon BEV reorientation with an eye to international developments (in markets, technology, competitors).

The German case's evolution also exhibits a good fit with the expected conceptual pattern as resistance strategies gradually strengthened during the first four periods to oppose the *direction* of change (towards electrification). In the first period (1970–1983), German automakers mostly ignored climate change and used no resistance strategies. In the second period (1983–1995), they used moderately strong framing, lobbying strategies, and organised pressure strategies to successfully weaken climate policies and avoid targets. In the third period (1995–2007), German automakers used framing strategies to ward off more specific policies, making voluntary pledges and promises that more sustainable cars would soon be on the road. In the fourth period (2007–2015), German automakers used framing strategies and strong lobbying strategies to successfully weaken EU vehicle emission policies, receiving significant help from German politicians willing to protect car industry interests. In the fifth period (2015–2025), automakers continued to use strong framing and lobbying strategies, but the focus changed towards *slowing the pace* of change. A deviation from the conceptual pattern is that German automakers also (partly) continued to contest the direction of change, successfully pushing for inclusion of e-fuel ICEs in the European ZEV policies (which opened the possibility of maintaining German strength in internal combustion technologies).

The Japanese case's evolution shows more significant deviations from the predicted pattern, mainly because early and pro-active reorientation towards HEVs (in the second and third period) was accompanied by limited resistance strategies. In the first period (1970–1990), attention to climate change by Japanese automakers was too weak to incite substantive change. In the second period (1990–1997) and third period (1997–2009), they accepted the climate science and only used some lobbying strategies abroad to amend rather than oppose California's ZEV policy, aiming to ensure HEVs qualified. In the fourth period (2009–2022), however, dominant automakers started to strongly oppose BEV policies at home and abroad, using framing, lobbying and organised pressure strategies (Table 4). The reason for contesting this *direction* of change is that BEV-centred electrification threatened their interests in both HEVs and ICEVs. Resistance strategies weakened somewhat in the fifth period (2022–2025), when Japanese automakers (reluctantly) diversified towards BEVs and shifted efforts towards *slowing the pace* of change. Nevertheless, Japanese automakers continue to leverage framing, lobbying and organised pressure strategies to dispute the direction of travel and muster ongoing support for HEVs (e.g. by positioning them as 'electrified vehicles' in marketing and policy discourse).

6. Conclusions

The case studies and comparative analysis show that incumbent automakers in the US, Germany, and Japan have long opposed and delayed a low-carbon transition towards battery electric vehicles, using a multitude of resistance strategies, including information, framing, lobbying, confrontational, and organised pressure tactics. The prevalence of different types of resistance strategies varied, with US automakers using more overtly antagonistic strategies (e.g. science contestation, litigation) whereas German and Japanese firms relied more on lobbying, consultation and revolving doors.

Resistance strategies also evolved over time, although there was variation between the three cases. The resistance of US automakers was strong from early on, as policymakers introduced significant technology-forcing policies (ZEV-mandate) in the second period. Automaker resistance strategies only weakened in the fifth period. The resistance of German automakers strengthened gradually over time, peaking in the fourth and fifth periods when they first opposed and then aimed to weaken European ZEV policies. Japanese automakers, in contrast, hardly resisted in the first three periods (because of their early HEV reorientation), but strongly opposed BEVs in the fourth period, and somewhat less strongly in the fifth period.

Notably, in all three cases, automakers continued to use resistance strategies in the fifth period – even as they simultaneously embarked on significant diversification efforts, making large investments in EV plants and supply chains. Incumbent firm resistance should thus not be understood as a *temporary* strategy that is only present in early transition stages. Instead, our conceptual framework and empirical evidence show that resistance is an *ongoing dimension*, present in multiple phases of low-carbon reorientation, but changing over time in terms of focus and type of strategy. Because firms operate in several arenas and play 'multi-dimensional chess', they can simultaneously resist and reorient, especially in later phases.

Another important finding is that the focus of resistance strategies in later phases shifted from opposing the *direction* of travel towards hampering the *speed* of change. All three cases show that while automakers presently see BEVs as the most likely future trajectory, they still seek to delay this transition to prolong the profitability of ICE- and hybrid-based business models. That said, German and Japanese automakers also aim to keep other trajectories open (such as e-fuel, FCEVs or HEVs), while Trump's return and 2025 policy reversals led US automakers to delay but not abandon BEV reorientation. Since none of the automakers in our cases have fully reoriented towards BEVs (phase 5 in our model), resistance strategies are likely to continue in the coming years. Significant pressure for full reorientation may, however, come from increasing competition from Chinese firms, who benefit from continued BEV deployment in the Chinese market (Fig. 1), ongoing battery cost reductions and rising attractiveness in emerging BEV-markets outside China.

Our findings hold relevance beyond the automotive sector, because resistance to low-carbon transitions occurs in many industries [5,6,102]. Our research on the temporal evolution of resistance strategies suggests that that the general industry playbook is to first ignore, deny, or obfuscate the climate change problem (through information and framing strategies), then resist or weaken climate-relevant policies and targets (through framing, lobbying, confrontational, or organised pressure strategies), and then to delay the speed of low-carbon transitions while simultaneously asking for financial support (through framing, lobbying, or organised pressure strategies). We suggest that this playbook is relevant beyond the car industry, and hope that future research will confirm or refute this hypothesis by investigating resistance strategies in industries that are in earlier low-carbon transition stages (like agrifood, chemicals, or steel) or in later transition stages (like electricity).

While our research identified and explained general patterns, the cases also showed country-specific deviations. These related to variations in company strategies (e.g. the significance of Toyota's and Honda's leadership) and country-specific contextual pressures (e.g. policies, policymaking styles, public debates, and market demand). Future research could thus fruitfully investigate resistance and reorientation strategies of automakers in other countries like China, South Korea, or France.

Although the article mostly focused on comparative research, the country case studies also showed several instances of transnational influence: a) US policies (such as California's 1990 ZEV mandate and the 1993 PNGV) stimulated radical innovation by German and Japanese automakers in the 1990s; b) strong US market demand for HEVs in the 2000s reinforced HEV-reorientation strategies by Japanese automakers, and led to strategic responses from German and US firms; c) the exposure by US regulators of emission test cheating led to the Dieselgate scandal that tarnished German automakers and led to stronger German and European policies; d) China's rapid expansion of BEV markets and BEV production after 2015 influenced policies and firm strategies in Japan, Germany and the United States. These transnational influences imply that the three cases are not entirely independent, and that automakers (and policymakers) also strategically respond to developments in other jurisdictions. Future research of other global industries (like steel, agrifood, or chemicals) could fruitfully further investigate such transnational influences.

More generally, we hope that our analysis will stimulate further research on the temporal dimension of resistance strategies, as this topic has hitherto received insufficient attention in debates about the speed of low-carbon transitions as well as in the climate obstruction literature.

CRediT authorship contribution statement

Frank W. Geels: Writing – original draft, Project administration, Methodology, Formal analysis, Conceptualization. **Karen Smith Stegen:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Gregory Trencher:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Peter Wells:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors confirm that they have no conflict of interest.

Data availability

Data will be made available on request.

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