Research Policy 54 (2025) 105198

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Technology discontinuation as a continuous process: diesel, sustainability, and the politics of delay

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ARTICLE INFO

Keywords:
Phase-out
Transitions
Diesel
Innovation
Sociotechnical imaginaries
Sustainability

ABSTRACT

The discontinuation of technologies - such as combustion engines, coal and nuclear power generation, or certain types of plastics - has become central to debates on sustainability, public health, and safety. Much of the existing literature and policy discourse, however, treats discontinuation as a discrete, well-defined phase at the end of a technology's lifecycle and as the implicit flipside of technology introduction. In this article, we propose conceptualizing discontinuation as a continuous process that unfolds throughout the entirety of a technology's lifespan, playing a critical role in its long-term survival. Drawing on a longitudinal, in-depth case study of diesel cars in Europe, we analyze how significant discontinuation pressures have existed for decades, repeatedly challenging, destabilizing, reconfiguring, and ultimately re-stabilizing diesel as a socio-technical system. We present a framework that captures how discontinuation efforts emerge, gain credibility, evolve, or are dismissed in relation to broader, stable imaginaries of socially desirable futures. In the case of diesel, we find that discontinuation efforts and counter-efforts specifically engaged two competing imaginaries of sustainability - one focused on local air quality and the other on global climate change - which allowed actors to strategically frame and rationalize the technology in ways that served their interests. By viewing discontinuation controversies as an inherent and continuous feature of a technology's durability, new policy options come to the fore. These include the need to shift the focus from the technology in question to what persists underneath, challenging the stability of underlying sustainability framings rather than merely reacting to moments of crisis. It also entails scrutinizing the politics of delay and the "technological neutrality", which tend to favor continuation, and treating discontinuation policy more seriously as a form of innovation policy supported by long-term strategies, toolkits, and equivalent levels of funding.

1. Introduction

In September 2015, the U.S. Environmental Protection Agency (EPA) issued a warning that the car manufacturer Volkswagen had systematically cheated on emissions tests using a "defeat device" capable of identifying test environments and selectively switching to low-emission modes. In the months that followed, the "Dieselgate" scandal reverberated across continents. Other car manufacturers were implicated, senior executives were fired or went to jail, and legal actions were taken in several countries. The scandal combined multiple storylines, including corporate (ir)responsibility and greed; a reaffirmation of diesel's reputation as a "dirty" technology; calls for retrofitting diesel engines; and scrutiny of emissions test setups. Some analysts predicted that Dieselgate would deal a death blow to the technology and, indeed, manufacturers' sales and stock market values plummeted in the years following 2015. Yet, to date, the industry has managed to avoid outright bans and continues to muddle through, with many actors doubling down on the "clean diesel" narrative that had emerged in previous years. Today, diesel cars are alive and well in Europe. Their greatest challenge is not the Dieselgate legacy of pollution, which has all but disappeared from

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https://doi.org/10.1016/j.respol.2025.105198
Received 18 January 2023; Received in revised form 20 November 2024; Accepted 6 February 2025
Available online 19 February 2025
0048-7333/

the public debate, but rather the warring geopolitics affecting fuel prices and the rising market share of electric cars. Although there are some indications of future bans on internal combustion engines more broadly,[1] these forays remain far in the future, politically fragile, geographically limited, and arguably incremental, with considerable uncertainty regarding the fate of existing (older) cars, all of which puts into question whether there will ever be a decisive shift concerning diesels.[2]

This paper is not primarily concerned with the Dieselgate scandal and its intricate details. Instead, it seeks to interrogate the politics of failed discontinuation attempts – in this case, through the history of diesel and combustion engines more broadly. In the automotive sector, the diesel engine has consistently retained a problematic image – a flawed, inefficient, dirty, and occasionally scandalous technology – repeatedly on the verge of disappearing "at any moment".[3] These decades of controversy prompt us to challenge the common understanding of discontinuation (or phase-out[4]) as a distinct phase at the end of a technology's lifecycle, in which innovation, diffusion, maturity, and decline neatly follow one another (Geels and Schot, 2007; Koretsky, 2023; Turnheim and Geels, 2012). Instead, we suggest that much can be gained by recognizing discontinuation attempts as integral to technology continuation - a constant process of plausibility negotiations, reconfigurations, and re-stabilizations that characterizes the entirety of a technology's lifespan. In other words, discontinuation is a continuous thread woven into the very fabric of a technology's existence. While it makes sense for some purposes to theorize discontinuation as an innovative achievement against incumbency (Levain et al., 2015), for other purposes, it may be more appropriate to understand continuation as an active achievement of maintenance work in response to ever-present discontinuation pressures (Graham and Thrift, 2007; Jackson, 2014; Sardo et al., 2021).

With our work, we build upon and extend the "continuous discontinuation" argument put forth by Levain et al. (Levain et al., 2015, p.24) and similar arguments on *innovation through withdrawal* (Goulet and Vinck, 2012; Goulet and Vinck, 2017; Goulet and Vinck, 2023a), which show how specific technology bans can inadvertently lead to the stabilization of entire socio-technical regimes. Furthermore, we draw on recent research on the rebounding dynamics of technological decline (Koretsky, 2023). Our work also responds to the call for a more critical understanding of "shocks and temporality" (Turnheim, 2023, p.68), moving beyond a narrow focus on disruption opportunities to instead provide a longer-term view of the stabilizing dynamics that frame "uncertainty, anticipation and imagination" (ibid.). In doing so, we expand a productive line of research on the "power of incumbent actors for resistive purposes" (Turnheim, 2023, see also Stegmaier, 2023; Stirling, 2019; Turnheim and Sovacool, 2020) and how the disruptive promise of innovation always needs to be locally plausibilized in ways that do not fundamentally threaten socio-economic orders (Pfotenhauer et al., 2023).

Our key argument is that the continued survival of highly contested technologies (such as diesel, nuclear power, plastics, etc.) can only be understood against the backdrop of broader, underlying interpretative frameworks within which proposed (dis)continuation must make sense. That is, we need to interrogate discontinuation efforts as part of broader *sociotechnical imaginaries* of desirable forms of social life related to certain technologies (Jasanoff and Kim, 2015) – and, more precisely, how discontinuation proposals and counter-proposals for continuation are strategically articulated, mobilized, contested, or sidelined in relation to various (and often competing) durable visions of socially desirable futures.

In what follows, we propose a four-pronged analytic framework to capture the "continuous discontinuation" dynamics vis-à-vis such durable sociotechnical imaginaries based on the following dimensions: sociocultural embedding, strategic positioning, the construction of windows of opportunity, and material and epistemic path dependencies. Applying this framework to the in-depth case of diesel cars in Europe, we show how diesel has been rationalized and judged in terms of its perceived benefits and risks, what ideas of progress have been associated with it, whether and when discontinuation appears preferable or even necessary, and which fixes have been permitted to delay or prevent its phase-out.

2. Sociotechnical imaginaries of sustainability and a framework for "continuous discontinuation"

2.1. Innovation, transitions, discontinuation

Discontinuation as an explicit topic of social science scholarship remains relatively under-researched, though it has gained considerable momentum in the last decade (Turnheim, 2023; Stegmaier, 2023; Koretsky et al., 2023a; Stegmaier et al., 2014; Turnheim and Geels, 2013). Elements of discontinuation and the phasing out of socio-technical systems can be found in various fields and literatures, including public policy, organizational studies, innovation studies, and science and technology studies. For instance, policy scholars have examined the phenomenon of "policy termination", which may exert a direct or indirect influence on socio-technical systems and their legacies (Bardach, 1976; DeLeon, 1978; Kingdon, 1984). Organizational and management scholars have investigated the effects of technological disruption and how companies handle sweeping internal changes vis-à-vis existing commitments, as well as the trade-offs and tensions that may emerge in such contexts (Berry, 2010; Christensen, 2013; March, 1991; Tushman and O'Reilly, 1996).

To date, the most extensive scholarship on discontinuation stems from innovation and transition studies, particularly in the context of sustainability transitions[5] (Grin et al., 2010; Schot and Kanger, 2018). Sociotechnical transitions are typically analyzed as sequential stages in which potentially disruptive technologies are introduced into niches, gradually mature and scale through variation and reconfiguration, and ultimately (though not always) evolve into new dominant systems (Geels and Schot, 2007; Geels and Schot, 2016; Rip and Kemp, 1998;

[1] In March 2023, the European Parliament approved the legislation to ban the sale of new ICE cars and vans from 2035. However, due to the pressure from certain European countries, such as Germany, Italy, and Poland, an exemption was granted for cars that run on e-fuels. https://www.euronews.com/green/2023/03/22/eu-to-ban-petrol-and-diesel-cars-by-2035-heres-why-some-countries-are-pushing-back. Additional agreements to transition away from fossil fuels have been initiated at COP28, in 2023.

[2] For example, a number of German politicians in the current election season are currently exploring the possibility of lifting the ban, echoing similar debates elsewhere. See e.g., https://www.zeit.de/politik/deutschland/2024-05/verbrenner-verbot-friedrich-merz-auto, https://www.politico.eu/article/italys-meloni-denounces-ideological-madness-of-eu-ban-on-gas-and-diesel-cars/?utm_source=LinkedIn&utm_medium=social.

[3] See https://www.nature.com/articles/news040202-13; https://www.japantimes.co.jp/news/2000/12/16/national/tokyo-bans-dirty-diesel-vehicles/; https://www.bbc.com/news/world-europe-30368504.

[4] In this paper, we primarily use the term "discontinuation" (as opposed to alternative terms such as "phase-out" or "exnovation") because it reflects the core of our symmetry argument, namely that continuation and discontinuation are interrelated. That is to say, discontinuation should not be regarded as a final stage, which might limit policy options and learning opportunities, but rather, in many instances, as crucial for continuation. While conceptual distinctions between these terms can be made (see, e.g., Callorda Fossati et al., 2023; Rinscheid et al., 2023), our focus rests with their shared emphasis on processes that eliminate technologies (or socio-technical systems) from routine use for various reasons. As such, we use these terms somewhat interchangeably.

[5] For a recent literature review on the concepts used to describe the various processes involved in terminating a socio-technical system, see e.g. Turnheim, 2023; Stegmaier, 2023; Rosenbloom and Rinscheid, 2020.

Smith et al., 2005; Pfotenhauer et al., 2022). Transition studies have yielded important insights into the intertwined systems of technological design, policy, use patterns, and institutions that emerge around, and stabilize, innovations, occasionally growing into stable, self-reproducing socio-technical regimes (Holtz et al., 2008). Incumbent organizations and the coalitions supporting them occupy a privileged position in shaping these environments, creating technological path-dependencies and political economies that are often unfavorable to change and prone to regulatory capture (Meadowcroft, 2011; Newig et al., 2008; Upham et al., 2015). At times, incumbent coalitions actively resist change (Geels, 2014; Hess, 2014; Lockwood et al., 2019), which is one of the reasons why continuation is often treated as the "normal" state of a sociotechnical system, as the regime is constantly reproduced and kept in check by those who profit from its survival (Turnheim and Geels, 2013; Dosi, 1982; Unruh, 2000).

In these studies, considerable attention has been devoted to the innovation side of transitions (Godin and Vinck, 2017; Koretsky et al., 2023b). Discontinuation often features only indirectly in the involuntarily displacement of incumbent technologies and systems (Levain et al., 2015; Andersen and Gulbrandsen, 2020; Tushman and Anderson, 1986) – a sort of zero-sum game related to Schumpeter's *creative destruction*, whereby some technologies vanish as a result of the emergence of superior alternatives. Geels (Geels, 2002), for instance, investigated how steamships developed against an existing path-dependent sailing ship regime, with the latter gradually but steadily losing ground to the former due to a combination of protected niches, strategic market positioning, and greater economic efficiency. The focus here is on the relative inferiority of existing technologies compared to emerging ones and the seemingly inevitable success of the latter, rather than on the social negotiations and power struggles that determine why certain technologies prevail or fail (Pinch and Bijker, 1984; Smith et al., 2010). With the conceptual and empirical focus of transition studies firmly on innovation, stabilization, and scale (Goulet and Vinck, 2017), discontinuation and the dynamics leading to it have been implicitly relegated to a distinct and final phase of a seemingly natural innovation trajectory (Turnheim and Geels, 2012; Turnheim and Geels, 2013; Johnstone and Stirling, 2020).

Recently, a number of authors have begun to delve more deeply into the governance of discontinuation processes (Stirling, 2019; Koretsky et al., 2023a; Goulet and Vinck, 2023b; Shove, 2012), mostly in the context of sustainability transitions (Turnheim and Geels, 2013; Geels and Penna, 2015; Hoffmann et al., 2017; Rogge and Johnstone, 2017). Here, discontinuation can refer to the deliberate termination of a sociotechnical system, often triggered by the recognition of a problem and involving complex, distributed governance processes (David, 2017; Heyen et al., 2017; Kivimaa and Kern, 2016; Rosenbloom and Rinscheid, 2020). According to Stegmaier and colleagues (Stegmaier, 2023; Stegmaier et al., 2014; Stegmaier et al., 2021), discontinuation patterns may vary significantly, ranging from deflection or incremental changes, to substantial adjustments (e.g., when a trajectory persists, but within constraints) and complete phase-outs (Turnheim and Geels, 2012; Turnheim and Geels, 2013; Newig et al., 2019). These works assess the specific circumstances under which discontinuation triggers arise and gain traction (Koretsky, 2023; Normann, 2019). This involves examining, for example, the "symbolic" and "cognitive" dimensions associated with a technological system (Koretsky and van Lente, 2020). A related concept, destabilization, describes "the process of weakening reproduction of core regime elements. (…) [That is], the process through which an existing regime loses its grip on firms-in-an-industry" (Turnheim and Geels, 2012, p.35; see also Roberts, 2017). Turnheim (Turnheim, 2023) suggests that destabilization arises from a conjunction of gradual, cumulative changes and discrete events, the intensification of which leads to destabilization patterns. In these situations, incumbents may perceive threats as either long-term or short-term shocks, thereby prompting varying degrees of radical responses (Stirling, 2019; see also Sardo et al., 2021).

Some scholars have argued that transitions from the old to the new are rarely clear-cut. The enduring materiality of many existing systems - and the epistemic communities surrounding them – make old technologies linger alongside new ones, often preventing their wholesome discontinuation (Edgerton, 2007). This perspective recasts the focus from supposedly sweeping, end-of-life inventions to the continuous, multiple, mundane practices of everyday technology use, which vary across people and communities and can co-exist for extended periods. Shove (Shove, 2012) also highlights the importance of analyzing instances of industry resurgence, revival, and the persistence of past configurations to better understand transitions. From this viewpoint, the relationship between innovation and discontinuation seems rather serpentine, suggesting that the ideal of new technologies displacing old ones may be naive altogether.

2.2. *Understanding continuities in discontinuation: a sociotechnical imaginaries approach*

One of the initial prompts for our research relates to Turnheim's (Turnheim, 2023, p.56) observation that "destabilization is tied to processes of stabilization in multiple ways". This suggests that stabilization and destabilization should not be viewed as merely "opposite, reverse or symmetrical processes" (ibid.). Our aim is to analyze the dialectical relationship between continuation and discontinuation efforts, and how each attains or loses credibility and support in a given context. We also shed new light on the tensions between long-term and short-term reasoning, as well as the role of incumbency as part of durable structural conditions.

To that end, the concept of *sociotechnical imaginaries*, as initially developed by Jasanoff and Kim (Jasanoff and Kim, 2009), provides a useful theoretical entry point. Sociotechnical imaginaries refer to "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, […] animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff, 2015a, p.4). These imaginaries represent the relatively stable interpretive canvas against which technological initiatives - including discontinuation pressures - acquire meaning within their particular *socio-cultural embedding*, and how such endeavors are assessed in relation to existing, broader understandings of the common good. In the U.S., for example, cars and car-centric mobility are frequently associated with "freedom", whereas in Germany they are often linked to the "German Engineering" culture and more recently to conflicts between urban and rural lifestyles. In both contexts, technologies are implicated in larger narratives of progress, identity, and sustainability (Miller et al., 2015; Miller and Wyborn, 2020). These imaginaries not only shape collective understandings of the past, present, and future but also influence what are seen as the most pressing challenges, plausible solutions, and legitimate pathways for change (Pfotenhauer et al., 2023; Jasanoff and Kim, 2015; Beck et al., 2021; Milkoreit, 2017). Although the concept of sociotechnical imaginaries has primarily been employed to investigate the uptake of novel technologies (such as nuclear power or genetic modification) in societies, we propose that it can be symmetrically applied to study the discontinuation of technologies. Indeed, a study by Felt (Felt, 2015) on how Austria's post-WWII identity was partly built around a shared understanding of "keeping technologies out" already points in this direction.

Imaginaries are neither universal nor static (Hess, 2015; Miller, 2020). While some imaginaries may become regionally dominant, they often coexist in tension with alternative and competing ones (Jasanoff, 2015a, p.4; see also Levy and Spicer, 2013; Mager, 2017; Mutter and Rohracher, 2022). This multiplicity means that discontinuation efforts may seem more or less plausible depending on the imaginary against which they are judged or how well actors manage to frame them to fit prevalent imaginaries. As we shall see, diesel engines have been framed as "undesirable" due to local air pollution but simultaneously as "desirable" and "effective" in combating global climate change when compared to gasoline engines. By extension, some actors claim diesel is beneficial (or at least better) for sustainability relative to gasoline, while others contend that it is simply part of the same unsustainable technological regime of internal combustion engines.

In other words, the interpretive flexibility of diesel vis-à-vis the diverse sociotechnical imaginaries that advocates and opponents can tap into allows for what we might call *strategic positioning* in discontinuation settings. The interpretive flexibility of social phenomena (Pinch and Bijker, 1984; Latour, 1987; Stone, 2012) and the recognition that categories employed to structure the world are essentially contestable (Boltanski and Thévenot, 2006; Gallie, 1955; Haraway, 1991; Jasanoff, 1987) have long been staples of constructivist social science. In practice, stakeholders can have – and, more importantly, can plausibly defend – different views on what the problem is, what the desirable solution should look like, and therefore on what functionalities and design features a technology should have. In this sense, stakeholders may argue both *for* or *against* diesel on environmental grounds or strategically employ different interpretations of "sustainability", "fairness", or "feasibility" (Miller, 2000). Bijker, Pinch, and colleagues argue that the dominance of certain technological designs and systems is not due to their intrinsic superiority but the result of particular social groups dominating the struggle to prioritize "their" version of the problem (Pinch and Bijker, 1984; Bijker, 1995; Bijker, 1993).

In the energy sector, for example, both coal companies and labor unions have argued that a rapid coal phase-out would be "unfair" to workers and coal-dependent regions, emphasizing potential job losses and economic disruptions. These actors have occasionally formed uneasy alliances with those from the fields of national security and environmental sustainability, particularly on issues such as increased short-term dependency on fossil fuel imports from geopolitically unstable regions or continued reliance on nuclear power. Other environmental advocates, in contrast, may emphasize the unsustainability and unfairness of climate change burdens on future generations and the urgency of addressing the global climate crisis, which already disproportionately affects vulnerable populations. The resulting "ideal" system configuration is thus not a natural optimum, but rather the outcome of political struggles over whose definitions and problems matter. Moreover, these dynamics do not unfold on a "green field", but are preconfigured and shaped by structural factors, including wider discursive frames, cultural norms, institutional arrangements, material path dependencies, and other forms of power (Jasanoff, 2012; Sovacool and Hess, 2017; Williams and Edge, 1996).

How, then, do imaginaries – and, with them, the perceived sustainability or unsustainability of technologies and practices – change over time? In his work on "vanguard visions", Hilgartner (Hilgartner, 2015, p.34) explored how "relatively small collectives (…) formulate and act intentionally to realize particular socio-technical visions of the future that have yet to be accepted by wider collectives", precisely by strategically aligning with broader stabilized imaginaries. Vanguard groups of discontinuation, such as policy makers, environmental activists, entrepreneurs, and concerned citizens, will have to strike a delicate balance between exploiting the legitimacy and plausibility conferred by widely shared imaginaries while challenging these dominant settlements (Hilgartner, 2015; see also Beckert, 2016; Brown et al., 2000; Delvenne, 2017; Jasanoff, 2015b). For example, Wentland (Wentland, 2016) and Engels et al. (Engels et al., 2019) show how an innovation initiative in Germany was deliberately realigned with shifting policy priorities - from energy transitions to smart cities to mobility transitions - to ensure its survival. In their study of regional innovation cultures, Pfotenhauer et al. (Pfotenhauer et al., 2023) investigate how innovation initiatives need to tap into broader cultural references and narratives and align themselves with established political cultures in order to be perceived as legitimate, carefully navigating the fine line between "promises of novelty and disruption associated with innovation and the need for continuity and social cohesion that allows actors to garner support" (see also Pfotenhauer and Jasanoff, 2017). Building on their argument about the plausibility of innovation processes in a given context, one could argue that "not every proposed [discontinuation][6] is imaginable or deemed desirable in each context, and in many instances, the very notions of '[discontinuation]', 'necessity' or 'desirability' are contested among local actors and communities". Proposals for discontinuation must contend with established social identities (e.g., the "long-distance driver"), forms of state support (e.g., commuter subsidies that lower taxes on selected fuels), or ways of visualizing problems or virtues (e.g., pollution maps), all of which makes the terrain in which vanguard visions navigate complex. These works on vanguard visions and innovation cultures echo with research on alignment in socio-technical transitions (Goulet, 2021) and innovation processes (Fujimura, 1987; Fleck et al., 1990).

Strategic positioning can also involve allowing one discontinuation to prevent another. In their 2015 study, Levain et al. (Levain et al., 2015) showed that the phase-out of dichlorodiphenyltrichloroethane (DDT) in most cases took the form of outright bans that emerged under specific cultural and legal circumstances. The authors highlight how these bans spurred strategic coordination activities by the incumbent industry and, paradoxically, increased the legitimacy of other pesticides. That is, partial discontinuation successes for DDT ultimately reinforced the broader socio-technical regime of pesticide usage, arguably undermining the ban's intended purpose. The authors define this phenomenon as "continuous discontinuation", which they describe as the persistence of the broader regime despite the discontinuation of a specific technology. In our paper, we expand the concept of "continuous discontinuation" to refer not only to the continuation of regimes but also to the survival and restabilization of particular technologies despite (and partly because of) constant onslaught of discontinuation attempts. In contrast to the case of DDT, the diesel car has yet to face an EU-wide ban, despite repeated and mounting calls for its phase out, with diesel repeatedly seeming just one scandal away from potential annihilation. If we want to move forward in critically analyzing phase-outs, we first need to recognize that discontinuation and continuation are always co-present and mutually constitute each other.

The strategic positioning of (dis)continuation relates to perceived *windows of opportunity* such as the Dieselgate scandal. The innovation and transitions literature typically points to a combination of factors, mechanisms, power dynamics, and chance as key elements that must align to overturn the status quo and replace existing technologies with alternatives, often by nurturing such alternatives in protected niches (Geels and Schot, 2007; Rip and Kemp, 1998; Geels and Penna, 2015). A variety of factors may drive these windows of opportunity, including elements beyond the direct control of system actors. Such factors encompass geopolitical conflicts, pandemics, oil price fluctuations, as well as longer-term shifts such as climate change and demographics (Elzen et al., 2011; Geels, 2006; van Driel and Schot, 2005). In some circumstances, actors may act as "policy entrepreneurs" (Kingdon, 1984; Flanagan et al., 2011), proactively creating and encouraging favorable conditions for change. This may include the implementation of strict command-and-control regulations (Rogge and Johnstone, 2017), such as bans on asbestos, CFCs, DDT (Levain et al., 2015; Maguire and Hardy, 2009; Sexton, 1986), leaded fuels, incandescent light bulbs (Stegmaier et al., 2014; Kierkegaard, 2014), and nuclear power plants (Pfotenhauer et al., 2012; Glaser, 2012). Purposeful and targeted public interventions thus play a pivotal role in triggering discontinuation processes (Stegmaier, 2023), as systems do not typically change spontaneously for the "better" (and, as discussed above, "better" is an essentially contested category in the first place) (Johnstone and Stirling, 2020; Stirling, 2014; Kropp, 2015; Sardo, 2022).

For our purposes, a key question is when and why seeming windows

[6] In the modified quote, we replaced the term "discontinuation" with "innovation".

of opportunity do not amount to an actual discontinuation. According to Actor Network Theory, controversies are always trials of strength between competing sociomaterial networks in their (more or less explicit) struggle for dominance (Akrich et al., 2002; de Laet and Mol, 2000; Latour, 1992; Law, 2009). From this perspective, framing discontinuation challenges as a one-off, object-centered event is misleading. Instead, it is a complex, multi-sited, continuous, and laborious effort requiring the disentanglement of a technology from a plethora of existing socio-material practices and identities (Koretsky, 2023; Shove, 2012; Barry, 2013). What is more, efforts to remove technologies from socio-material networks need to confront both inertia and active counter-efforts to maintain the network and its distribution of power as is. Keeping the diesel car regime alive involves, for example, continuously maintaining a global assemblage that connects Saudi Arabian oil rigs to German automakers, to public investments in road infrastructures worldwide, to commuting patterns and employers' home-office rules, to catalytic chemicals and European regulations. This is closely related to Goulet and Vinck's (Goulet and Vinck, 2012; Goulet and Vinck, 2017) work on "innovation through withdrawal", in which they investigate how innovation operates by way of "dissociation and detachment mechanisms". Incumbent stakeholders often engage in strategic counter-work to fend off alternative socio-technical assemblages (and hence alternative ways of living), thus keeping certain technologies alive as obligatory passage points (Stirling, 2019; Pfotenhauer et al., 2023; Miller et al., 2013). In this respect, sociotechnical imaginaries are key to understanding the traction that discontinuation controversies can or cannot garner, which detachments are deemed plausible, as well as how the ground is prepared for opportunities to manifest and become actionable (or not). Upon closer inspection, windows of opportunity are rarely surprising but are the expression of deeper conditions of possibility and shifts in underlying paradigms that have been underway for some time (Pfotenhauer et al., 2023; Jasanoff, 2003; Jasanoff, 2004). This underscores the continuous character of discontinuation, as proposed in this article.

This last point also speaks to the role of *material and epistemic path dependencies* that often prevent discontinuation. Material infrastructures and design lock-ins play a key role in the resilience of specific social practices (Dosi, 1982; Anderson and Tushman, 1990; Pickering, 1995; Star and Ruhleder, 1996) and are a key aspect in transition studies. As "politics by other means" (Latour, 1988; Latour, 1991; Verbeek, 2006; Winner, 1980), they regulate social behavior, perceptions, and choices, often invisibly and with starkly unequal effects. Material path dependencies have also been discussed in recent literature on discontinuation (e.g., Koretsky, 2023; Turnheim, 2023; Shove et al., 2012), so we will not elaborate further on this aspect here. In contrast, less attention in discontinuation contexts has been paid to epistemic path dependencies and their role in preventing discontinuation – i.e., stabilized ways of knowing and evaluating that may go unquestioned but support the status quo. From an STS perspective, the stability of epistemic practices is closely related to the stability of material practices (Jasanoff, 2004). Knowledge practices are often institutionalized and codified as a mix of scientific and technical standards, legitimate forms of expertise, and material procedures (e.g., testing), which provide durable cultural and political inscriptions that shape our societies (Beck and Mahony, 2018; Haas, 1992; Jasanoff, 2013; Miller, 2004). For instance, national census statistics and disease classifications are based on categories that can only be modified at specific intervals, hence producing long-lasting and occasionally unwieldy political consequences (Bowker and Star, 1999). Similarly, it has taken several decades to modify the method of testing vehicles for particulate emissions, which has evolved in tandem with diesel engines and testing technologies, as well as with progress in medical and environmental knowledge. Discontinuation efforts thus face the dual challenge of re-making not only material systems but also the epistemic structures through which we collectively assess the validity, value, and trade-offs of such systems. This is consistent with recent literature on "deep" transformations (Stirling, 2019; Schot and Kanger, 2018; Beck et al., 2021).

2.3. Summary of the theoretical framework for continuous discontinuation

Based on the above theoretical foundations, we propose a four-pronged framework for analyzing discontinuation as a *continuous process* against the backdrop of broader socio-technical imaginaries. The framework includes four dimensions: socio-cultural embedding, strategic positioning, windows of opportunity, and material-epistemic path dependencies (Table 1). These dimensions are partly interrelated. For instance, windows of opportunity for diesel bans in Europe are shaped by their cultural and institutional embeddedness (e.g., in the evolving EU regulatory landscape). Rather than sharply delineated variables, these dimensions offer focal points for empirical analysis, elucidating key aspects of continuous discontinuation.

3. Research design and data collection

To test our analytical framework, we adopted a longitudinal case study approach (Van de Ven, 2007; Yin, 2009; Yin, 2012), focusing on a discourse analysis of the recent history of diesel engine cars in Europe. We selected this specific case because these technologies (along with many others, including nuclear power plants, self-driving cars, and artificial intelligence) have faced criticism since their inception. While initially the main line of attack was based on measures of efficiency (defined as the conversion of energy into motion), particularly in comparison to rival technologies, from the 1960s onwards, environmental concerns began to influence the criteria for defining efficiency or the

Table 1
Analytic framework to study discontinuation as a continuous process.

	Dimensions of Sociotechnical Imaginaries	Research questions
1	Socio-cultural embedding	• How do technologies relate to situated understandings of the common good? How are they framed differently across various contexts? • What counter-visions exist? How do vanguard visions (e.g., those of entrepreneurs or policy-makers) gain plausibility, credibility, and traction? • How do local political cultures deal with the risks, opportunities, or legitimacy of change?
2	Strategic positioning	• Who gets to define the problem and the corresponding range of solutions? Whose interests are served by these problem definitions? • How do actors shape the contested meanings of concepts such as sustainability, feasibility, affordability, or safety? • How do actors strategically draw on diverse imaginaries to further their agendas? • How is the plausibility of both continuation and discontinuation constructed?
3	Windows of opportunity	• When does discontinuation seem more (or less) plausible or desirable? • What are the deeper underlying conditions for a window of opportunity to emerge and become actionable? • How has a technological system dealt with previous episodes of discontinuation? • How much time should be allowed for the creation of socio-technical technical "fixes" that grant the system a temporary license to continue operating?
4	Material-epistemic path dependencies	• How do existing infrastructures, bodies of knowledge, and assessment techniques shape public perceptions of the technology? How are they shaped in return? • What alternative knowledge and concerns need to be considered to make discontinuation plausible?

introduction of other evaluation measures. Despite existing opportunities to terminate or at least limit the spread of diesel cars, many European legislators and car manufacturers framed these engines as a critical technological solution to temporarily fix some pollution-related mobility problems. These persistent threats of discontinuation provide an opportunity to study the set of negotiations through which the plausibility of discontinuation versus continuation was constructed and compared.

Yet, the history of the diesel engine is long, layered, and full of twists and turns, and this case study cannot hope to cover all its aspects (for a more in-depth discussion, see Berggren et al., 2009; Hård, 1994; Hård and Jamison, 1997; Knie, 1992; Knie, 1991). Indeed, our analysis does not aim to provide a comprehensive chronology of the diesel socio-technical system's developments in Europe. In line with our framework, we investigated how calls for both the continuation and phase-out of diesel cars in Europe have been strategically aligned with two imaginaries of "air quality". These are: (Geels and Schot, 2007) *global pollution*, related to greenhouse gases (GHGs) and particularly CO_2 emissions (Section 4.1), and (Koretsky, 2023) *local pollution*, with reference to pollutants such as sulfur oxides, nitrogen oxides, volatile organic compounds, and particulate matter (Section 4.2). Due to how it has been strategically positioned vis-à-vis these two imaginaries, the diesel automobile has been forced into association with emerging technological developments, groups of actors, laws and regulations, economic and risk models, normative concerns, social and political structures, infrastructures, and political agendas.

Our work is empirically based on the triangulation of different data sources and follows a two-step data collection procedure. First, after an initial document review, we conducted preliminary semi-structured interviews in 2019–20 (Eisenhardt and Graebner, 2007), each lasting approximately 60 min. Interviewees included stakeholders from the automobile and air quality arenas in Europe, including scientists from the EU's Directorate for Air Quality, environmental NGOs, automobile associations, and other researchers and policymakers involved in personal mobility and pollution issues at national and international levels. The interview structure was partly informed by the literature (Flick, 2014) and aimed to gather background information on the recent history of the diesel engine, including its major technical advances, barriers to innovation, the role of environmental regulations for and against innovation, and how regulations and pollution testing procedures have evolved. The interviews were recorded and fully transcribed for analysis.

After this phase, we carried out a secondary, in-depth document analysis of archival and other document sources, such as European legislation and other institutional communications; reports from, e.g., independent research institutes and universities, the automotive industry, environmental organizations, and other NGOs; scientific articles and books; and, to a lesser extent, newspapers. This textual corpus, consisting of more than 200 documents, is only partially cited in this article (the full list of analyzed documents is available in Appendix A). We collected documents using a snowball sampling technique: starting with items cited by interviewees or identified during the initial desk research, we then analyzed documents mentioned in these texts, and so on, until thematic saturation was reached and no new information relevant to our research objectives emerged. We excluded documents that were irrelevant to understanding the dynamics shaping the diesel car system (e.g., too technical or merely naming diesel cars), or its relationship to competing technologies, innovation, and related social concerns (e.g., "air quality", health).

The entire corpus of selected documents and interviews was analyzed using a qualitative data analysis software (Atlas.ti). We used open coding categories, partly derived from the literature outlined in Section 2, which allowed us to be flexible in the face of novel findings. The triangulation of different data sources uncovered key events, controversies, imaginaries, and vanguard visions, as well as how certain visions were co-constructed and issues framed (e.g., through models, thresholds, and visualizations techniques), and then materialized in legislations and actionable plans, and how these visions and interpretations evolved over time.

The following section (Section 4) presents introductory information on the recent history of diesel cars in Europe, highlighting the challenges this technology has faced since its inception. Sections 4.1 and 4.2, respectively, discuss the relationship between the two imaginaries of global and local sustainability and how they were connected to the diesel car system. Although they are presented separately, these sections are inevitably intertwined.

4. (Dis)continuing diesel cars in Europe

The diesel engine was invented in the 1890s with the aim of efficiently converting heat into mechanical work (Bryant, 1976). However, it took approximately two decades for Rudolf Diesel and his collaborators to develop a reliable technology that could compete with the most optimized steam engines. From the outset, diesel technology was surrounded by controversy and stigma. Manufacturers across Europe were hesitant to adopt the diesel engine in automobiles for at least three reasons. Firstly, the traditional German automobile industry, in particular, was reluctant to embrace new engine designs. This stemmed from the fact that a consensus had already been reached regarding the technical structure and design principles of gasoline engines, and thus the organization of a tailored supply chain (Knie, 1991, p.268–269). Secondly, the diesel engine was commonly perceived as heavier, dirtier, and underperforming compared to its rivals (Hård and Jamison, 1997; Meyer and Manheim, 1980). In Germany, it was negatively described as "unattractive" and "unsophisticated" (Knie, 1991, p.236). Thirdly, early diesel engines emitted a pungent odor, which was expected to be problematic in urban areas and for short journeys. As a result, the early heavy and bulky diesel engines were predominantly employed in large transport applications, including trains, trucks, ships, submarines, and stationary applications. From the 1930s onwards, more compact diesel engines gained a foothold in the mass production of passenger cars, partly due to the impetus from military technological-industrial developments. Between the 1930s and 1960s, support for diesel cars grew significantly in both the automobile industry and political circles, grounded in their higher mileage and lower fuel consumption. However, their power performance still lagged behind that of gasoline vehicles (Dingle and Lai, 2005; Reif, 2014; Smil, 2010). This situation began to change during the oil and environmental crises of the 1970s, when the automobile industry was suddenly faced with demand for greater fuel efficiency and resource conservation. Thus, the attributes of being "efficient" and "more economical" gained importance and were leveraged by car manufacturers to improve the image of diesel cars and maintain the dominance of the combustion engine regime as a whole. Diesel developments were now proposed as a credible short-term solution to the crisis, and heralded as an expression of the European industry's innovativeness. This selective exploitation of the positive associations with diesel to bolster the automotive industry's image would become a recurring strategy in future discontinuation debates. For the first time, the diesel engine was promoted as a respectable "rival" to the gasoline engine, no longer relegated to a niche market (Canzler and Knie, 1994).

The increasing debates on resource efficiency, energy security, and the environment also set the stage for two major controversies regarding the desirability of diesel and internal combustion engines. The first controversy arose from growing concerns about *global climate change*, particularly the need to reduce or offset CO_2 emissions. In this context, between the 1990s and the 2010s, the automotive industry and

European regulators frequently promoted the diesel engine as an *interim* technology with lower CO_2 emissions compared to other gasoline-based internal combustion engines (Metz et al., 2001; Schipper and Fulton, 2009).[7] Over time, this evolved into an enduring narrative of diesel's superiority in terms of power (*torque*) and combustion efficiency, thus giving it an image of relative sustainability (Cames and Helmers, 2013; Poliscanova, 2017). As a result, the market share of diesel cars in Europe increased significantly within 20 years. The second controversy, instead, linked environmental and public health concerns to *local air quality*, which is responsible for approximately seven million premature deaths worldwide each year, as well as other health risks, including respiratory and cardiovascular diseases (IARC, 2012; UNECE, 2014). These risks were associated with the emission of pollutants – such as nitrogen oxides (NO_x) and particulate matter (PM) – which tend to remain geographically localized. Although vehicles are not their primary source in absolute terms, they emit them in areas where people live and work. The pollution problem with diesel cars was recognized as early as the 1960s (Bryant, 1976; Canzler and Knie, 1994), making their widespread adoption in Europe a trade-off with public health. In response, many countries implemented specific regulations and institutions related to emissions, albeit at varying paces, legal regimes, and standards (cf. below). More broadly, for much of its recent history, diesel cars in Europe have been associated with competing imaginaries of sustainability through the notions of "fuel efficiency", "pollution", and "health" – often strategically leveraged against one another as multiple ways of framing the situation, as well as for particular use scenarios in individual passenger mobility, such as long-distance hauls.

4.1. The "global air quality" sustainability imaginary: diesel as a temporary fix for CO_2

Fuel economy and air quality issues have been high on the European political agenda for several decades, although their framing and focal points have evolved over time. While much of Europe's support for diesel was initially built on the opportunity presented by the oil crises of the 1970s and in the wake of the pollution-centered environmental movement from the late 1960s, European concerns about climate change in the 1990s took on a specific shift towards GHG emissions (Díaz et al., 2017). CO_2 was identified as the most voluminous man-made gas (United Nations, 1992; United Nations, 1997), and motorized road traffic was flagged as a special "cause for concern". This was not only because it produced the majority of transport-related CO_2 emissions, but also due to the rapid growth of the car market, especially for heavier, more powerful, and less fuel-efficient vehicles (IEA, 1999; Commission of the European Communities, 1995a).[8]

To address CO_2 emissions from transport and encourage energy savings, EU member states entered into a voluntary, non-binding agreement with leading car manufacturers' associations (ACEA, JAMA and KAMA). The industry committed to reducing sales-weighted CO_2 emissions per kilometer of newly sold cars on a fleet-average basis by 2012, using "cost-effective solutions" (European Parliament, Council of the European Union, 1994; European Parliament, Council of the European Union, 2009, p.3).[9] By translating the "global air quality" problem first into "global GHG emissions" and then into European fleet-wide (average) emission standards for passenger car sales, global air quality issues became addressable in Europe through technological innovations that would enhance fuel efficiency and minimize CO_2 releases.[10] As these agreements left it up to manufacturers to decide how to meet the agreed targets, the car industry quickly promoted a technology readily available in its portfolio as an *interim* fix to boost the average fuel efficiency of its fleets: the diesel car (Commission of the European Communities, 1998a; Commission of the European Communities, 2001a; Commission of the European Communities, 2000).[11]

Demonstrating the plausibility of diesel's superiority in fuel economy, and thus as a solution to global GHG emissions, was a complex process that required carefully constructed narratives and supporting evidence. This entailed defining, agreeing on, and rigorously measuring various parameters, including fuel consumption, social mitigation costs, per-kilometer CO_2 emissions, and engine power (see Commission of the European Communities, 1995a, p.5–6; Schipper et al., 2002). It was also strategically important to emphasize clear distinctions between diesel and gasoline engines, so that they could be mobilized for different purposes and in various market segments. For example, car manufacturers, environmental experts, and economists highlighted that diesel fuel contains more energy per liter than gasoline and that diesel engines consume less fuel per vehicle-kilometer (as CO_2 g/km targets were set with the European Commission; Harding, 2014; Scholl et al., 1996, p.12[12]). Conversely, the fact that diesel fuel emits more CO_2 per unit of energy was downplayed. On a broader GHG-basis, taking into account the carbon content of the fuel, the advantages of diesel vehicles would have been partially offset (An et al., 2007). Although diesel was strategically framed as an interim solution to GHG concerns, the IEA (IEA, 2000, p.19) accused many mainstream policy organizations of failing to acknowledge climate change as a "compelling problem for the present generation" and of often pointing to persistent scientific debates about the supposed timing and severity of GHG damage. According to this perspective, the rapid uptake of diesel vehicles suggested a widespread reluctance to tackle the socio-material factors contributing to the rise in car usage, such as uncontrolled urban sprawl or insufficient investment in public transport infrastructure. It also reflected a hesitation to enforce stricter CO_2 emission regulations (ibid.). Diesel automobiles, in fact, allowed automakers and European policymakers to delay implementing more radical changes in transport technologies and mobility patterns, thus maintaining the business as usual.

To maintain its image as the "least harmful" option with associated sustainability benefits, and hence to mitigate the risk of an outright ban on combustion engines for the automotive industry in general, the diesel engine also had to continue evolving. The primary technological

[7] Also – according to some scholars - to address Europe's overproduction of middle distillates and establish a domestic market for these vehicles (Cames and Helmers, 2013; Nesbit et al., 2016).

[8] See Commission of the European Communities, 1995a; Commission of the European Communities, 1996a; Keay-Bright, 2001; Council of the European Union, 1991; Commission of the European Communities, 1998b.

[9] EU regulations and standards have differed from those implemented by other countries. For example, the approach to GHG emissions in the US CAFE standards on fuel economy was based on vehicle footprint rather than vehicle weight, as in the EU (Nesbit et al., 2016). Furthermore, the U.S. did not differentiate between technologies when setting emission standards for pollutants such as NOx and CO (ibid., p.15; Hascic et al., 2009).

[10] It should be noted that GHG emissions were not the sole rationale for improving engine consumption. There were additional considerations, including the goal of reducing the European Union's dependence on energy imports and forecasts of fossil fuel shortages.

[11] Manufacturers also worked to improve the fuel efficiency of gasoline cars and to develop alternative and dual-fueled vehicles. The European Commission's overall strategy on CO_2 emissions from passenger cars also included promoting car fuel efficiency through fiscal measures and designing a consumer information scheme on fuel economy (European Parliament, Council of the European Union, 1999).

[12] However, the relative fuel efficiency of a vehicle depends on several factors, including its weight, aerodynamics, engine power, driving style, road conditions, and tire characteristics.

challenge for automakers was to "optimize [the car] simultaneously against the criteria of comfort and reliability, safety, noxious emissions, and fuel consumption" (Commission of the European Communities, 1995a, p.6; Meyer and Manheim, 1980). Some of these criteria were often strategically portrayed as conflicting - for instance, reducing vehicle weight versus safety, or introducing components to minimize nitrogen oxides rather than CO_2 emissions (Commission of the European Communities, 1995a; Commission of the European Communities, 2007a, p.9–10). The pressures to improve fuel economy and vehicle performance led, among other things, to the widespread adoption of Turbocharged Direct Injection (TDI) diesel engines, common rail direct fuel injection systems, enhanced energy control management systems, and reductions in driving resistance and friction losses (Cames and Helmers, 2013; Commission of the European Communities, 1998a; Commission of the European Communities, 2001b; Commission of the European Communities, 2005; Hickey et al., 2014).

Especially with the introduction of common rail technology, (…) diesel smoke became so fine that it was no longer visible. So diesel was marketed as "clean": it meets the latest standards, smoke is no longer seen, low fuel consumption, low CO_2. It was considered a "clean kit technology" at the time. So you no longer had to be ashamed of driving a diesel engine [automobile association representative].

These technological advancements were not solely based on technical and economic considerations. Rather, the voluntary agreement signed by automakers hinged on EU-level measures designed to provide institutional support for diesel as a relatively "cleaner" option (Commission of the European Communities, 1998a). These measures included the "unhampered diffusion of CO_2-efficient technologies" in the European market, which led to more favorable excise duties on hydrocarbons and reductions in registration or sales taxes, annual circulation taxes, and company car taxes across Member States (Harding, 2014; Council of the European Union, 2003).[13] Overall, while manufacturers were busy making diesel cars as attractive and comfortable to drive as existing gasoline cars, along with a "superior fuel consumption" narrative (Commission of the European Communities, 2001a; Knecht, 2004), Europe-specific policy interventions made them more affordable to purchase and use (Schipper et al., 2002; Hascic et al., 2009). At the same time, the diesel efficiency trope was regularly mobilized as evidence of steady progress in internal combustion engine technology in general, providing a justification to slow down any discontinuation attempts. The EU's pro-diesel policies and underlying narratives effectively transformed Europe into a "diesel island" (Poliscanova, 2017) and created a stable regime where a selective sustainability imaginary supported the co-production of specific technologies, standards, and use practices.[14]

This long-term preference for diesel was accompanied by widespread controversy. Advocacy groups argued that government subsidies conflicted with the EU's funding principle of technology neutrality (Commission of the European Communities, 1996a). Furthermore, they claimed that the apparent efficiency gains of diesel cars were offset by the rebound effects stemming from changing mobility patterns: diesel drivers tended to prefer larger, safer, and more comfortable cars – which were heavier and hence less fuel efficient – and, on average, diesels were often driven more frequently due to their lower cost per kilometer, making them the preferred choice for commercial purposes (e.g., taxis, sales, hauling) and high-mileage private drivers (Schipper and Fulton, 2009; Commission of the European Communities, 2005; Fontaras and Samaras, 2007; Schipper and Fulton, 2013). More importantly, this focus on diesel did not address the fundamental issue of a carbon-centered mobility system, nor did it adequately tackle concerns about local pollution and public health (cf. Section 4.2).

In the early 2000s, the established narrative framing diesel as a CO_2 savior began to crumble, along with the ambiguity that could be wielded between different combustion technology options. The EU's annual reports evaluating manufacturers' progress in reducing CO_2 emissions indicated that they consistently failed to meet the assigned targets (Commission of the European Communities, 2004; Fulton, 2012). Meanwhile, the European Council and a diversifying political landscape, increasingly influenced by "green" parties, began to question the heavy reliance on diesel engines as a sustainable solution for CO_2 emission reduction. Furthermore, critics argued that automakers had relied almost exclusively on the TDI engine's progress and other minor innovations while adhering to broader material path dependencies, thus delaying the adoption of more efficient solutions, such as engine downsizing, weight reduction, and hybrid vehicles (Fulton, 2012; Zierock, 2012).

In their defense, car manufacturers attempted to shift the focus of the controversies to planned improvements in diesel engines and drive trains, energy management systems, the increased applicability of biofuels, and new chassis designs. The key message - and a trending topic for marketing departments - remained that CO_2 emissions were a competitive field for diesel automakers. Despite this, in 2009, the inadequacy of CO_2 emissions reductions from passenger road transport was acknowledged by a growing political consensus in Europe, resulting in the introduction of mandatory CO_2 standards for passenger cars (European Parliament, Council of the European Union, 2009; European Environment Agency, 2018; Nesbit et al., 2016). This regulation set a target of 130 g/km for the average fleet of all manufacturers combined by 2015. In practice, the allowed CO_2 emission level for each manufacturer was determined based on the average vehicle weight of their fleet. For the EU, stricter regulations were the only way to push both diesel and gasoline vehicles to their technological limits regarding CO_2 emissions reduction, while also incentivizing a gradual, long-term shift towards sustainable transportation modes such as fuel cell vehicles and hydrogen fuels (IEA, 2009, p.114; Commission of the European Communities, 2007b). These stringent measures could have provided the European automotive industry with a "long-standing competitive advantage" and positioned Europe as a global "leader in fuel efficiency in the field of clean and lean technologies" (Commission of the European Communities, 2007c, p. 9).

Other reports in the late 2000s and early 2010s contributed to the gradual erosion of the narratives surrounding diesel superiority, which had been carefully constructed in the 1990s. Critics argued that diesel engines were inherently more expensive to manufacture; their CO_2 emissions were higher due to the greater carbon content of diesel fuel per unit of energy and, consequently, claims of fuel efficiency misled consumers (European Environment Agency, 2020, p.8; Schipper and Fulton, 2009; Harding, 2014). Finally, the gradual decline in diesel vehicle market share in Europe since 2013 had not significantly impacted total CO_2 emissions from cars, which some analysts interpreted as evidence of significant distortions in CO_2-based vehicle taxation systems that disproportionately favored diesels (Transport and Environment, 2018). The *Dieselgate* scandal certainly contributed to this process of making discontinuation a plausible option. As pressure to phase-out diesel cars grew, a parallel debate surfaced concerning emissions testing methods in light of research exposing the inadequacy

[13] This Directive has continued to favor diesel vehicles over time. Furthermore, (Commission of the European Communities, 2011) acknowledged that it had resulted in "unfair competition between fuel sources and unjustifiable tax benefits for certain types of fuel (…), and [failed to] address the need to reduce CO_2 emissions".

[14] While this was the case for Europe as a whole, it is worth noting that there were national differences. Between 1995 and 2009, Belgium and Luxembourg exhibited the highest degree of "dieselization", followed by France and Austria (https://www.eea.europa.eu/data-and-maps/figures/dieselisation-in-the-eea). Additionally, it is noteworthy that in the early 1990s, the adoption of diesel cars in both Europe and Japan was comparable, at around 10 % of the fleet. Nevertheless, while Japan proceeded to phase out diesel cars within a few years, Europe continued to endorse their use (Cames and Helmers, 2013, p.3). Indeed, Japan had made an earlier commitment to invest in hybrid vehicle technology.

of the existing NEDC test in accurately detecting CO_2 emissions or fuel consumption. It further uncovered a widening gap between the results of official laboratory CO_2 tests and real-world driving emissions (Transport and Environment, 2015; Mock et al., 2012).[15] Automakers have since being accused of meeting CO_2 targets largely through exploiting test flaws,[16] using defeat devices to artificially lower CO_2 figs. (Transport and Environment, 2016), and benefiting from regulations that favored heavier, more powerful vehicles (Poliscanova, 2017). Yet, the paradigmatic test setups available and the regulatory science underpinning them had been in use for decades, proving challenging to change overnight.

Unsurprisingly, however, despite the strong backlash that followed the Dieselgate scandal, automakers were reluctant to abandon diesel entirely. Instead, they proposed remedies such as synthetic fuels and other eco-innovations (ICCT, 2020). Reaffirming the plausibility of earlier narratives, they argued that Europe could not have achieved such substantial CO_2 emission reductions without the high share of diesel vehicles: diesel technology, they claimed, "is a key enabler for cutting emissions" (ACEA, 2016, p.7–8).

I think diesel will have its future. With regards to CO_2 emissions, there is a big advantage. (…) From my point of view, it will take a few years, but then diesel will come back. If we look at CO_2 and e-mobility (…): that is not CO_2 free. We do not have, and will never have, CO_2-free electricity [ICE engines expert].

Ironically, the automakers even invoked the same principle of technology neutrality previously used against diesel vehicles, to oppose what they described as targeted discrimination against "the latest generation of diesel vehicles – emitting very low pollutant emissions on the road", contending that "any significant move away from clean diesel technology will provide additional challenges to meeting post-2021 CO_2 targets" (ACEA, 2017, p.1). As a result, the narrative of diesel as a "bridging technology" with ambivalent effects has allowed it to survive Dieselgate while positioning it as a key ingredient in national strategies for achieving post-2021 CO_2 targets.

4.2. The "local air quality" sustainability imaginary: pollutants and the city

The "local air quality" sustainability imaginary strikes a very different, yet in many ways complementary, register to that of global GHG concerns. First, with over 75 % of the population living in cities "where most exceedances of the air quality reference levels occur" (UNECE, 2014), controversies surrounding diesel pollutants have been firmly focused on local environmental pollution and public health concerns. Second, although residential, commercial, and institutional energy consumption, as well as other activities, remain significant contributors to urban pollution in absolute terms, road transport has garnered increasing attention since the 1960s due to the rise in vehicle flows in confined urban spaces and its proximity as a source of pollution to our respiratory systems (Hickey et al., 2014; Commission of the European Communities, 2018; CAFÉ, 2004). Early regulatory efforts addressing local pollution include the U.S. Clean Air Act of 1963 and the European Air Quality Directive of 1970. Over time, these standards have been tightened repeatedly (Knie, 1989, p. 3) and adopted by institutions such as the WHO (WHO, 2003; WHO, 2006), the International Agency for Research on Cancer (IARC, 2012), and the EEA (Pastorello and Mellios, 2016).

An important milestone in cementing the connection between diesel cars and the local pollution imaginary was the 1989 classification of diesel exhaust gases as "probably carcinogenic to humans" by the IARC. As sales of diesel vehicles continued to soar, this declaration prompted political responses from European regulators. As with climate change debates, a cooperative approach was taken between government and industry stakeholders to address the issue (Commission of the European Communities, 1995b, p.6; see also Commission of the European Communities, 1995a; Knie, 1989, p.3), resulting in the *Auto-Oil I* and *II Programmes*, aimed at "providing policy-makers with an objective assessment of the most cost-effective package of measures to reduce emissions" (Commission of the European Communities, 2000; see Commission of the European Communities, 1996a; Commission of the European Communities, 1996b). The language of expertise and standards set out in these documents concerning the relationship between fuels, engines, and emissions, became an enduring reference point and framework for future diesel-related debates, as well as the basis for the drafting of the first EU emissions standards.

In this context, a key opportunity to shape the future of diesel cars was the construction of the definitions of "feasibility" and "cost-effectiveness" that were used to assess the emission-reduction solutions that could "reasonably be expected" from the industry. To prevent jeopardizing diesel's perceived role as the best short-term solution to CO_2 and energy security issues, policymakers initially allowed for more lenient NOx and HC emission thresholds for diesel compared to gasoline cars (cfr. automobile association interview; see also Cames and Helmers, 2013, p.12). This decision reflected a clear prioritization of energy efficiency over public health issues (Coria, 2012; ICCT, 2014; Sterner and Coria, 2012). As a result, compliance with increasingly strict European standards (Euro 1–3) was achieved with minimal technological advancements (Sanchez et al., 2012; Haum and Petschow, 2003).[17] In contrast, the introduction of more radical pollution-abatement technologies - such as Exhaust Gas Recirculation (EGR) and Diesel Particulate Filters (DPF),[18] both of which were already available and widely used in other diesel engine applications (Boulter et al., 2012; König et al., 2001) - was postponed because, according to car manufacturers, their technical problems were difficult to solve, and their introduction would have significantly increased cars prices (Arp, 1993; Friedrich et al., 2000; Goodwin, 1999).

"The forecast [made by] car manufacturers (…) was that particulate traps would be expensive [to introduce], and that due to the particulate traps regeneration fuel consumption would increase and engines would be destroyed due to the high back-pressure. (…) [But when] manufacturers were forced by law to introduce [them], nothing happened. [By doing this], manufacturers saved a lot of money, because it took years to introduce these technologies - and a manufacturer that does not innovate is actually saving money [cfr. automobile association representative]".

In the meantime, pressure from civil society grew to prioritize public health in addressing pollution. For example, in Germany during the early 2000s, the campaign "Kein diesel ohne Filter" (No diesel without

[15] In 2004, the European Environment Agency stated that there was "increasing evidence that the standardized test cycles used for the type approval of vehicles do not necessarily represent real-world driving conditions" (European Environment Agency, 2004)

[16] According to Mock et al. (Mock et al., 2012), the NEDC test did not account for technological advancements. Furthermore, due to its predictability, it was easy for manufacturers to "optimize CO_2 and pollutant emissions for the corresponding operating points of the engine to achieve lower emission levels during type approval" (p. 2–3).

[17] Euro standards are not prescriptive; they indicate which tests must be carried out and which emission limits must be met for each pollutant. They do not mandate the introduction of a specific technology to solve a problem.

[18] European automakers claimed that the DPF was the most promising solution to comply with the Euro 5 standard (Haum and Petschow, 2003, p.23). However, one car manufacturer introduced it well ahead of the agreed timeline among manufacturers, thus revealing that it was possible to reduce particulate emissions to levels well below the requirements of the EU standard without incurring significant cost disadvantages. This development increased both pressure and embarrassment (Cames and Helmers, 2013, p.10; Haum and Petschow, 2003; see also https://dieselnet.com/news/1999/04peugeot.php).

filter) was coordinated by the NGO *Deutsch Umwelthilfe* and supported by various transport and consumer protection associations. This coalition accused the German car industry of obstructing the introduction of diesel particulate filters for more than a decade.[19] As one interviewee recalls:

A strong NGOs movement pushed for the introduction of this particulate filter. The industry disagreed (…). Eventually, the environmental organizations gained sufficient public and government support, and the particulate filter was introduced. (…) After that, the image of the diesel was good again [automobile association expert].

This and other episodes in the evolving controversy over local air quality and diesel are particularly instructive insofar they highlight the painstaking work undertaken by different actors over time in their struggle for dominance over the redefinition of the future of diesel cars, and how various technological options and policy framings have been pitted against more ambitious calls for discontinuation (see, e.g., Hickey et al., 2014; Boulter et al., 2012; König et al., 2001). Debates on design modifications in response to public health concerns and potential discontinuation threats have often involved finger-pointing between industry sectors and political actors over the allocation of undue burdens or the prevention of substantial progress in relation to new technologies (e.g., EGR, DOC, and Selective Catalytic Reduction - SCR). An interesting debate arose when car manufacturers accused the European Commission of unfairly placing the primary burden of cleaning up the air on them, rather than imposing fuel quality changes on oil companies. Car manufacturers portrayed the sulfur content in fuels as a key hurdle to improving urban air quality (Hickey et al., 2014; Blumberg et al., 2003), arguing that sulfur considerably limits the efficiency of post-combustion emission abatement devices (e.g. EGR, DOC, and SCR; Commission of the European Communities, 1996b, p.15; Commission of the European Communities, 1998a; Dixson-Declève, 2012). The petroleum industry objected to this proposal, arguing that it would violate the cost-effectiveness principle and have a detrimental environmental impact. To substantiate this position, they demonstrated how a reduction in sulfur would result in an increase in CO_2 emissions from refineries (Commission of the European Communities, 1996b, p.60; Commission of the European Communities, 2001c, p.4).

The oil industry told us that this was not possible, [and] the engine developers said "you are preventing us from future markets. [Asian manufacturers] will overrun us with their new engines". So a project started investigating how to take the sulfur out of the fuel during the refinery process. [ICE engine expert].

The sulfur issue sparked a lengthy debate between industry and governments, resulting in calls for further studies, demonstration projects, and the acknowledgement that refinery upgrades must be conducted gradually due to the significant infrastructure commitments involved. Car manufacturers attributed the postponement of the introduction of low/zero sulfur fuels to the EU, asserting that these fuels were instrumental in the adoption of novel, fuel-efficient, and less polluting engine technologies (Commission of the European Communities, 2002, p.12). Following protracted negotiations, it was agreed that sulfur would be phased out through a two-stage process (European Parliament, Council of the European Union, 1998a; European Parliament, Council of the European Union, 1998b). However, by making sulfur removal a complicated, lengthy, and costly process, both the automotive and oil industries benefited from the subsequent delays.

Another important element in understanding the efforts for the continuation and discontinuation of diesel cars is emissions testing. The testing regime relies on a wide range of interrelated models, technologies, procedures, experts, laboratories, and evolving scientific knowledge, and is therefore generally slow to change. One opportunity in this respect was the introduction of Real-Driving Emissions (RDE) testing, which verifies vehicle emissions in situ (European Commission, 2010; Pavlovic et al., 2018).

The RDE is the biggest revolution in the history of vehicle emissions testing. (…) With the RDE you put the laboratory on the car and you are out in the real world. This is something that engineers who developed after-treatment systems had [never] been confronted with; [therefore, until then,] it had never been a huge technological challenge [public official].

As previously explained, these tests indicated that diesel cars emit more particles than had previously been certified by standard laboratory tests (Franco et al., 2014). This finding contributed to the concerns that had been raised by the recent IARC statement (IARC, 2012)[20] on the carcinogenicity of diesel exhaust for humans from all sources (e.g., automobiles, trains, agricultural power generators, hospitals). Additionally, they questioned the effectiveness of some of the aforementioned technical solutions to pollution problems (e.g., SCR, LNT, and EGR; Yang et al., 2015).

The organization [that discovered the discrepancy] wanted to demonstrate (…) that you could lower the NOx limit in Europe way down, following the example of the US market - where diesels had to meet the same standards as petrol [cars]. Their surprising finding was that, among the batch of vehicles tested, (…) [some] performed pretty badly on the road, while they had managed just fine in the [laboratory] cycle. This triggered the EPA's investigation [public official].

However, the RDE tests did not immediately play a decisive role in ascertaining diesel performance. They underwent a validation process before becoming an official procedure, which did not happen until the EURO 6-temp stage in 2017. Therefore, the previous formal standards obfuscated the known truth and served the diesel continuation narrative for years. While *Dieselgate* represented a moment of public transparency, it emphasized a pre-existing gap between laboratory and real-world driving conditions, which had already been acknowledged by some political, industrial, and environmental groups (Weiss et al., 2013). Nevertheless, it is also evident that:

The Dieselgate scandal [caused] (…) rapid transformations, and it all happened under the eyes of the media, of politicians… This was a very unusual set of circumstances for a crowd that typically operates (…) behind closed doors and in cycles lasting five years [public official].

Moreover, pollution regulations and the testing regime have evolved in tandem with pollution models and the development of more accurate techniques and tools for data collection and analysis, which have continued to change over time. For example, while particles were initially measured solely by their mass, size became a determining factor in the 2000s (Haum and Petschow, 2003). Furthermore, before the late 1990s, local pollution models had a resolution of only 2 km^2, which prevented the identification of busy roads and other hotspots of regulatory concern (Goodwin, 1999, p.17). Based on changes in these knowledge bases and assessment techniques, some policy-makers implemented new strategies against pollution, such as Low Emission Zones based on driving restrictions.[21]

Debates over complex testing and modeling regimes, intertwined with technological options, have thus enabled pro-diesel groups to regularly sidestep windows of opportunity for stricter regulation. However, these very discussions have also allowed diesel critics – including environmentalists, vanguard groups promoting alternative technologies and lifestyles, regulators, and citizens – to steer the conversation more effectively towards its discontinuation.

[19] https://www.deutschlandfunk.de/kein-diesel-ohne-filter-102.html; http://www.umg-verlag.de/umwelt-medizin-gesellschaft/k_diesel.html.

[20] This communication was followed by a full report in 2013, retrievable at https://publications.iarc.fr/129.

[21] https://www.theguardian.com/business/2016/apr/23/diesel-cars-pollution-limits-nox-emissions, https://www.theguardian.com/cities/2018/nov/30/its-the-only-way-forward-madrid-bans-polluting-vehicles-from-city-centre.

5. Discussion: foregrounding continuity in discontinuation theory and practice

Our research on the diesel phase-out debates in Europe complements the existing discontinuation literature in important ways.

First, discontinuation dynamics are protracted, complicated, highly political, and messy. Our case study shows that these dynamics are not limited to a well-defined end-of-life phase of a technology, but a consistent feature throughout its entire lifespan. Diesel has never been an unequivocally accepted technology in Europe. On the contrary, phase out pressures have been a staple of its existence since its invention, and despite diesel's success, have prevented any form of permanent settlement. Our findings are consistent with the existing transitions literature (Turnheim and Geels, 2013; Schot and Kanger, 2018; Geels, 2006), which, nonetheless, tends to emphasize how technological, organizational or social innovations bump up against the "power of incumbent actors for resistive purposes" (Turnheim, 2023, see also Stegmaier, 2023; Stirling, 2019; Turnheim and Sovacool, 2020). Our study offers a complementary perspective on systems that persist despite the constant challenges. It demonstrates that this endurance is actively produced and stems precisely from the dialectical relationship between a system and its challenges. Continuation and discontinuation hence cannot be easily separated for analytical purposes, let alone in a temporal sequence.

Second, our analysis shows that the notion of "continuous discontinuation", originally introduced by Levain et al. (Levain et al., 2015, p.24), can be productively expanded to describe the fragile survival and constant need for repair of individual technologies, not just the stabilization of a higher-order socio-technical regime affected by a discrete technology ban. Put differently, the discontinuation debates surrounding diesel reveal the fragility of socio-technical assemblages and the constant work required to keep them together. "Technologies as configurations that work" are constantly threatened, repeatedly on the verge of being discontinued, actively rescued through what we might call "continuation work", and always subject to reinterpretation and reassembly in order to maintain certain power structures intact (Sardo et al., 2021; Akrich et al., 2002; Latour, 1992; Barry, 2013; Latour, 1990; Denis and Pontille, 2015).

Third and related, our case study reveals the key role of relatively durable sociotechnical imaginaries in mediating the dialectic between continuation and discontinuation – and, more broadly, between the plausibility of a socio-technical system and the plausibility of challenges to it. In the diesel debates, two principal imaginaries of sustainability were relevant – one concerning local air pollution and public health, and the other on CO_2 emissions and global warming – that both diesel's assailants and supporters repeatedly invoked to either build credibility or discredit their opponents. While these imaginaries are not per se incompatible - and many actors identified with both - they were actively leveraged against each other. This strategic positioning created openings to save diesel through a pro-sustainability framing, presenting it as the "more efficient solution" and "lesser evil", thereby warding off both local pollution concerns and broader sustainability critiques of combustion engines. Hilgartner's (Hilgartner, 2015) concept of "vanguard visions" is particularly relevant here, as it describes how certain groups propose and test disruptive visions by strategically, albeit tentatively, aligning them with broader, durable imaginaries to build socio-political alliances. This also underscores the relevance for discontinuation theory of Pfotenhauer et al.'s (Pfotenhauer et al., 2023) concept of "innovation cultures", which zooms in on how actors navigate a fine line between disruption and familiarity when seeking to plausibilize innovations into existing socio-technical fabrics. From this perspective, our research provides a deeper understanding of the stabilizing dynamics that shape "uncertainty, anticipation and imagination," as called for by Turnheim (Turnheim, 2023), and offers a more nuanced view of "shocks and temporality" beyond a sole focus on disruption. Seemingly disruptive events - such as the Dieselgate scandal, the introduction of new emission standards, and technological changes - occur against the backdrop of collectively shared normative understandings of the world (e.g., of "sustainability" or "desirability") that remain relatively stable over extended periods. The diverse discontinuation trajectories, such as deflection, incrementalism, or complete phase-outs, as observed by Stegmaier and colleagues (Stegmaier, 2023; Stegmaier et al., 2014; Stegmaier et al., 2021), can thus be interpreted as positioning dynamics within more durable interpretive frames of reference provided by sociotechnical imaginaries.

Our four-pronged analytic framework enabled us to capture the continuous discontinuation dynamics in greater depth:

- *Local socio-cultural embedding.* Diesel's discontinuation debates have taken specific regional, national, and transnational forms – from the initial diffusion of diesel cars in pre- and post-war national economies, through the emergence of discussions about fuel efficiency, climate change, and pollution, to current controversies over testing and industrial competitiveness, all the way to today's car-free urban space redesigns and the rise of alternative forms of mobility. In the EU, growing concerns about environmental protection have been articulated against long-standing corporatist alignments between industry and governments, with cities often taking the lead in implementing change due to the absence of clear (or daring) national and international regulations to protect citizens' health. These industrial and political cultures are not static or isolated, but instead influence one another (Hess, 2015; Miller, 2020).
- *Strategic positioning.* Throughout diesel's contested history, car manufacturers have strategically aligned with different socio-technical imaginaries to manage mounting concerns. For example, they maintained a distinction between global and local pollution narratives or articulated diesel's efficiency as a sustainability advantage over gasoline engines. This strategic positioning work, based on decoupling environmental challenges and prioritizing certain solutions, enabled the automobile industry to effectively delay attacks against internal combustion engines, create conditions for quick technical or policy fixes, and therefore prevent more substantial changes to the European mobility system.
- *Windows of opportunity*. Throughout diesel's history, several critical moments of destabilization (Turnheim and Geels, 2012; Turnheim, 2023; Turnheim and Geels, 2013) have emerged, but none amounted to a decisive blow. For instance, the oil and energy crises of the 1970s threatened the internal combustion engine as a whole, yet ultimately played out in diesel's favor due to its efficiency narrative. Similarly, the Dieselgate scandal deeply shook the "clean diesel" narrative but ultimately led to debates about testing setups, corporate greed, and the broader future of combustion engines, allowing diesel to survive between two competing sustainability imaginaries. In many instances, these windows of opportunity were countered by (promises of) temporary fixes, which circumvented and muted discontinuation debates, ultimately contributing to a "continuance pathway" for diesel (Stegmaier, 2023).
- *Material-epistemic path dependencies*. Path dependencies concern, first and foremost, the built infrastructure of the automobility system – including roads, supply chains, industries, and settlement structures – which make it difficult for vanguard actors to break with existing usage patterns in radical ways (Schot and Kanger, 2018; Beck et al., 2021). It also includes less obvious elements, such as established forms of expert knowledge inscribed, for example, in definitions, technical standards, testing procedures and associated technical devices, as well as local use practices (Barry, 2013; Bowker and Star, 1999; Jasanoff, 1990). As is common in technology controversies, political disputes were frequently translated into technical controversies about tests, devices reliability, or advances in pollution science, all roped together in practices of risk assessment and management. The stability of the diesel regime thus equally relied on the stability of the knowledge regimes underwriting it: what exactly counted as the "problem" or "advantage" of diesel cars – whether (in)

efficiency, pollutants, technological lag, fuels, usage patterns, or CO_2 – turned out to be quite malleable. The same is true for the "cures" invoked to solve problems, such as the introduction or removal of urea solutions, sulfur, cheating devices, and subsidies.

6. Conclusion: policy implications for discontinuations

Understanding discontinuation as an extensive, continuous process that unfolds against the background of relatively stable sociotechnical imaginaries has significant implications for how we should approach policy interventions.

First, policymakers should focus less on crisis moments and binary choices, and more on the conditions that enable a technology's survival, which are closely tied to the underlying imaginaries that allow actors to frame the technology as (ir)rational, (un)desirable, or (im)plausible. For example, if local and global pollution concerns were framed as interconnected rather than separate issues - a "*both-and*" rather than an "*either-or*" - diesel's continuation would likely seem far less plausible. Moreover, perceived crises and windows of opportunity for discontinuation are not per se qualitatively different from periods of normal operation; both depend on the strategic positioning of vanguard visions tested within a specific innovation culture (Pfotenhauer et al., 2023; Hilgartner, 2015). What some actors view as a crisis, others might see as irrelevant or even an opportunity for consolidation. Additionally, what might seem like critical moments to some might, in reality, just be episodes in the continuous process of making and unmaking ties (Goulet and Vinck, 2017; Goulet and Vinck, 2023b), set against the background of plausibility provided by long-standing imaginaries. Framing discontinuation as a binary decision point or as an end-of-life phase misses the larger picture. Instead, policy-makers should look across technologies to identify common framing strategies that allow technologies to survive or be phased out. While the discontinuation trajectories of individual technologies and systems inevitably differ, their plausibilization often draws on shared normative concerns and cultural references (Felt, 2015).

Second, the story of diesel is also a story about the politics of delay. Knowing how much discontinuation pressures have been a staple of diesel's history normalizes discontinuation as an option that is always present. But it also forces us to reckon with the reasons why none of these options was ever chosen. If discontinuation threats are indeed the norm, the key question becomes why societies choose to "discontinue discontinuation" during moments of crisis - and what the conditions are under which we allow discontinuation arguments to be dismissed. In particular, this puts the spotlight on the timeframes allowed for remedies to be developed, approved, and implemented, as well as for strategic realignment vis-à-vis changing sustainability imaginaries to take place. For diesel cars in Europe, mandates for stricter standards and legislation, or the enforcement of better tests and technologies, were repeatedly delayed, as were potential termination dates for the technology if no such remedies were found. These delays provided ample opportunities for intervention once the immediate pressures of controversies, such as Dieselgate, had blown over. Discontinuation policies must seek to address this temporal dimension more explicitly: How much time should be allotted for developing technological fixes? What defines a "realistic" time horizon for adaptation, as frequently demanded by industry? How long should a temporary fix be allowed to serve as a bridge? Should termination dates be tied to specific conditions? How narrowly technical should the framing of the problem be? More provocatively, how can we avoid trade-offs between the urgency of addressing climate change and local public health concerns, to trigger simultaneous rather than sequential action, thereby undercutting strategies to save diesel? Ultimately, the story of diesel can be told as one of asymmetric waiting periods granted to different possible trajectories, and of trade-offs between near-term and long-term futures.

Third and related, recognizing these structural imbalances suggests broadening the principle of *technological neutrality* to account for the de-facto continuation bias for established technologies. As we have seen, arguments for co-existence are always at once opportunities for delay and discursive repositioning. If we wish to take discontinuation seriously as a powerful tool for transition governance that recognizes all technology options, then it must truly, not just nominally, be on the table. In practice, a continuous formative assessment could take place to establish the conditions under which a technology should (continue to) receive a license to operate or be phased-out, considering not only economic and political opportunities but also the social context in which they are situated. Our analysis of the diesel cars in Europe suggests that "neutrality" is not a universal given, but a constructed, strategically used category that needs to be responsive to evolving knowledge systems, stakeholders' perspectives, and societal values (see also Pfotenhauer et al., 2023).

Finally, discontinuation policy should be developed as an active branch of innovation policy, supported with similar levels of funding and political attention. While there might be good analytic reasons to insist on differences, there might be pragmatic reasons to frame discontinuation more actively *as* innovation and benefit additional attention and resources (Pfotenhauer, 2023; Pfotenhauer et al., 2019). At the moment, innovation policy is almost exclusively focused on the creation of novel technologies and the related economic opportunities and social benefits. However, the economic and social opportunities from *discontinuation* might be just as important. Policy-makers could thus take a page out of the playbook of innovation toolkits to boost discontinuation efforts. For example, one could think about strategic funds and incubators for discontinuation, or more designated experimental spaces for regulatory and technology exceptions specifically targeting discontinuation attempts. Low-emission zones are already a step in this direction, somewhat comparable to principles of living labs (Engels et al., 2019). If we wish to treat discontinuation seriously as a lever to address unsustainable practices in energy, mobility, production and consumption – including in relation to emerging technologies – then we need to systematically build capacity in the form of expertise, policies, infrastructures, and funding, following the path of what happened for innovation policy 30 years ago.

CRediT authorship contribution statement

Stefania Sardo: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sebastian M. Pfotenhauer:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Funding

This work was supported by the BMBF Zukunftscluster "MCube".

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Relevant regulatory documents or analyses consulted for this study

Typology	Month/ year	Extended title
European Communities Council Directive	03.1970	70/220/EEC, On the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles
European Communities Council Directive	06.1991	91/441/EEC, amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles
United Nations Framework Convention	1992	United Nations Framework Convention on Climate Change, Kyoto, Japan
Commission of the European Communities Communication	05.1993	COM(93)47 Communication from the Commission to the Council and Parliament and the economic and social committee: Green paper on remedying environmental damage
Commission of the European Communities Commission Directive	12.1993	93/116/EC Adapting to technical progress Council Directive 80/1268/EEC relating to the fuel consumption of motor vehicles
Commission of the European Communities Working paper	03.1995	SEC(95)288 Commission working paper on the EU climate change strategy: a set of options
Commission of the European Communities European Parliament and Council Directive	03.1994	94/12/EC Relating to measures to be taken against air pollution by emissions from motor vehicles and amending Directive 70/220/EEC
Commission of the European Communities Communication	07.1995	COM(95)302 The common transport policy action programme 1995–2000
Commission of the European Communities Communication	12.1995	COM(95)689 A Community strategy to reduce CO2 emissions from passenger cars and improve fuel economy
Commission of the European Communities Communication	06.1996	COM(96)248 on a future strategy for the control of atmospheric emissions from road transport taking into account the results from the Auto/Oil Programme
Commission of the European Communities Communication	11.1996	COM(96)561 On environmental agreements
SAE International technical papers	1997	Noboru Hikosaka, A View of the Future of Automotive Diesel Engines
International Energy Agency Report	1997	Transport, Energy and Climate Change
European Commission Technical Working Group on Particles Position paper	04.1997	Ambient air pollution by particulate matter
European Commission Directorate-General XI, Working Group on Nitrogen Dioxide Position paper	11.1997	Position paper on Air Quality: nitrogen dioxide
United Nations Protocol	12.1997	Kyoto Protocol to the United Nations Framework Convention on Climate Change
Commission of the European Communities Communication	03.1998	COM(1998)204 On transport and CO2 - Developing a Community Approach
Commission of the European Communities Communication	07.1998	COM(1998)495 Implementing the Community Strategy to Reduce C02 Emissions from Cars: An Environmental Agreement with the European Automobile Industry
European Commission Press release	07.1998	Commission and ACEA agree on CO_2 emissions from cars
European Parliament and Council Directive	10.1998	98/69/EC relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC
European Parliament and Council Directive	12.1998	98/70/EC relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC
ACEA Commitment	1999	ACEA Commitment on CO2 emission reductions from new passenger cars in the framework of an environmental agreement between the European Commission and ACEA
International Energy Agency Report	1999	CO2 Emissions from Fuel Combustion: A new basis for Comparing Emissions of a major Greenhouse Gas
European Parliament and Council of the EU	1999	Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO2 emissions in respect of the marketing of new passenger cars
Commission of the European Communities Recommendation	02.1999	1999/125/EC On the reduction of CO2 emissions from passenger cars
European Commission, Standard & Poor's DRI and K.U. Leuven Report	08.1999	Auto-Oil II Cost-effectiveness Study. Part I: Introduction and Overview
Transport & Environment Report	12.1999	Controlling traffic pollution and the Auto Oil Programme
International Energy Agency Report	2000	The road from Kyoto. Current CO_2 and Transport Policies in the IEA
Commission of the European Communities Green Paper/Communication	03.2000	COM(2000)87 on greenhouse gas emissions trading within the European Union
European Parliament and Council Decision	06.2000	Decision 1753/2000/EC Establishing a scheme to monitor the average specific emissions of CO_2 from new passenger cars
European Automobile Manufacturers Association and the Commission Services Joint Report	07.2000	Monitoring of ACEA's commitment on CO_2 Emission Reduction from Passenger Cars (1995–1999)
Commission of the European Communities Communication	10.2000	COM(2000)615 Implementing the Community Strategy to Reduce CO_2 Emissions from Cars First annual report on the effectiveness of the strategy
Directorates General for Economic and Financial affairs, Enterprise, Transport and Energy, Environment, Research and Taxation and Custom Union Report	10.2000	The Auto-Oil II Programme. A report from the services of the European Commission
European Communities, Working Group On Arsenic, Cadmium And Nickel Compounds Position Paper	10.2000	Ambient air pollution by AS, CD and NI compounds.
AEA technology for the European Commission Report	11.2000	Consultation on the need to reduce the Sulphur content of petrol and diesel fuels below 50PPM: A policy makers summary
Working Group III of the Intergovernmental Panel on Climate Change Report	2001	Metz, B., Davidson, O., Swart, R., Pan, J., 2001. Climate Change 2001: Mitigation, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK
Commission of the European Communities White paper	2001	European transport policy for 2010: time to decide
Ricardo Consulting Engineers Report	05.2001	DETR/SMMT/CONCAWE Particulate research programme 1998–2001 Summary Report
Commission of the European Communities Proposal	05.2001	COM(2001)241 Proposal for a directive on the quality of petrol and diesel fuels and amending Directive 98/70/EC
Commission of the European Communities Press release	11.2001	Memo/01/354 Encouraging the use of alternative fuels for transport: frequently asked questions
Commission of the European Communities Communication	11.2001	COM(2001)643 Implementing the Community Strategy to Reduce CO2 Emissions from Cars Second annual report on the effectiveness of the strategy (Reporting year 2000)

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Typology	Month/ year	Extended title
Commission of the European Communities Communication	12.2001	IP/01/1814 Commission welcomes the mandatory introduction of sulphur-free petrol and diesel
Commission of the European Communities Working paper	06.2002	SEC(2002)1338 Commission staff Working Paper. Monitoring of ACEA's Commitment on CO2 Emission Reduction from Passenger Cars. Monitoring of JAMA's commitment on CO_2 Emission Reduction from Passenger Cars (2001). Monitoring of KAMA's Commitment on CO_2 Emission Reduction from Passenger Cars (2001)
Commission of the European Communities Communication	12.2002	COM(2002)693 Implementing the Community Strategy to Reduce CO_2 Emissions from Cars: Third annual report on the effectiveness of the strategy (Reporting year 2001)
World Health Organization Report	2003	Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. WHO, Bonn, Germany (http://www.euro.who.int/document/e79097.pdf)
Commission of the European Communities Directive	2003	Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity
International Council on Clean Transportation Report	2003	Blumberg, K.O., Walsh, M.P., Pera, C., 2003. "Low-sulfur gasoline & diesel: the key to lower vehicle emissions". Prepared for the International Council on Clean Transportation. Napa, CA, USA.
GRPE Report	07.2003	Report of the GRPE Particle Measurement Programme (PMP) Government Sponsored Work Programmes
Commission of the European Communities Directive	08.2003	2003/76/EC Directive amending Council Directive 70/220/EEC relating to measures to be taken against air pollution by emissions from motor vehicles
Institute for Energy Report	2004	Impacts of the increasing automotive diesel consumption in the EU, ed. Kavalov and Peteves
OECD Report	2004	Can Cars Come Clean? Strategies for Low-Emission Vehicles
Commission of the European Communities Communication	02.2004	COM(2004)78 Implementing the Community Strategy to Reduce CO2 Emissions from Cars: Fourth annual report on the effectiveness of the strategy (Reporting year 2002)
Commission of the European Communities Press release	02.2004	IP/04/195 CO_2 emissions from new cars in the EU down by more than 10 % since 1995
CAFE Working Group on Particulate Matter Position Paper	12.2004	Second Position Paper on Particulate Matter
Commission of the European Communities Communication	12.2005	COM(2005)683 Proposal for a Regulation (…) on type approval of motor vehicles with respect to emissions and on access to vehicle repair information, amending Directive 72/306/EEC and Directive …/…/EC
T&E – European Federation for Transport and Environment Report	2005	Reducing CO2 Emissions from New Cars. A progress report on the car industry's voluntary agreement and an assessment of the need for policy instruments. Ed. Per Kågeson
Commission of the European Communities Communication	6.2005	COM(2005)269 Implementing the Community Strategy to Reduce CO2 Emissions from Cars: Fifth annual Communication on the effectiveness of the strategy
Commission of the European Communities Working paper	6.2005	SEC(2005)826 Commission staff working paper. Monitoring of ACEA's Commitment on CO2 Emission Reductions from Passenger Cars (2003). Monitoring of JAMA's Commitment on CO2 Emission Reductions from Passenger Cars (2003). Monitoring of KAMA's Commitment on CO2 Emission Reductions from Passenger Cars (2003)
SRU German Advisory Council on the Environment Report	08.2005	Reducing CO_2 Emissions from Cars
Commission of the European Communities Communication	09.2005	COM(2005)446 Thematic Strategy on air pollution
TNO Science and Industry Report	10.2005	Euro 5 technologies and costs for light-duty vehicles. The expert panels summary of stakeholders responses
European Parliament Resolution	11.2005	European Parliament resolution on 'Winning the Battle Against Global Climate Change' (2005/2049(INI))
Wuppertal Institute for Climate, Environment and Energy Report	12.2005	Review of Voluntary Approaches in the European Union
Commission of the European Communities Working document	12.2005	SEC(2005)1745 Commission staff working document. Annex to the Proposal for a Regulation of the European Parliament and of the Council On type approval of motor vehicles with respect to emissions and on access to vehicle repair information, amending Directive 72/306/EEC and Directive …/…/EC. Impact Assessment
Commission of the European Communities Communication	12.2005	COM(2005)683 Proposal for a Regulation of the European Parliament and of the Council On type approval of motor vehicles with respect to emissions and on access to vehicle repair information, amending Directive 72/306/EEC and Directive …/…/EC.
European Commission Enterprise and Industry Directorate-General Report	2006	CARS 21. A Competitive Automotive Regulatory System for the 21st century
OECD/IEA Report	2006	Review. Energy Policies of IEA Countries
OECD Report	2006	Reducing NOx Emissions on the Road. Ensuring future exhaust emission limits deliver air quality standards
WHO Guidelines	2006	WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005
Commission of the European Communities Communication	06.2006	COM(2006)314 Keep Europe moving - Sustainable mobility for our continent Mid-term review of the European Commission's 2001 Transport White Paper
Commission of the European Communities Communication	08.2006	COM(2006)463 Implementing the Community Strategy to Reduce CO2 Emissions from Cars: Sixth annual Communication on the effectiveness of the strategy
T&E – European Federation for Transport and Environment Position paper	09.2006	EURO 5 and 6 emissions standards for cars and vans
European Commission. DIRECTORATE A - General Affairs Economic analysis, impact assessment, evaluation and climate change Consultation Document	2007	TREN.A2/EM/cc D(2007) Preparation of an Impact Assessment on the Internalisation of External Costs.
Working Group III to the Fourth Assessment Report of the IPCC Report/ Chapter	2007	Transport and its infrastructure
Commission of the European Communities Communication	02.2007	COM(2007)19 Results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles
Commission of the European Communities Working document	02.2007	SEC(2007)60 Accompanying document to the Communication from the Council and the European Parliament. Results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles Impact Assessment

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Typology	Month/ year	Extended title
European Parliament and Council Regulation	06.2007	715/2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information
PWC Report	09.2007	Impact Assessment on a new approach for the cleaner and more energy efficient vehicles directive proposal
PWC Report	09.2007	The automotive industry and climate change. Framework and dynamics of the CO_2 (r) evolution
MVV Consulting, Tractebel Development Engineering Report	09.2007	Preparation of a Green Paper on urban transport: Report on urban transport in Europe
European Parliament and Council Directive	09.2007	Directive 2007/46/EC Establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles
Commission of the European Communities Report	09.2007	Sustainable Urban Transport Plans. Preparatory Document in relation to the follow-up of the Thematic Strategy on the Urban Environment
Commission of the European Communities Communication/Green paper	09.2007	COM(2007)551 Towards a new culture for urban mobility
Commission of the European Communities Regulation/Communication	12.2007	COM(2007)856 Setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles
Commission of the European Communities Working document	12.2007	SEC(2007)1723 Accompanying document to the Proposal from the Commission to the European Parliament and Council for a regulation to reduce CO_2 emissions from passenger cars Impact Assessment
ECORYS Nederland BV Report	2008	Stakeholder Consultation. Report Green Paper on Urban Mobility
European Parliament and Council Directive	05.2008	2008/50/EC On ambient air quality and cleaner air for Europe
Commission of the European Communities Regulation	07.2008	692/2008 Implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information
International Energy Agency Report	08.2008	Review of international policies for vehicle fuel efficiency
International Energy Agency/OECD Book	2009	Transport, energy and CO_2. Moving toward sustainability
International Energy Agency Report	2009	How the energy sector can deliver on a climate agreement in Copenhagen
Commission of the European Communities Report	2009	COM(2009)279. A sustainable future for transport Towards an integrated, technology-led and user-friendly system
European Parliament and Council Directive	04.2009	Directive 2009/30/EC amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC
European Parliament and Council Regulation	04.2009	Regulation (EC) No 443/2009 Setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles
European Parliament and Council Directive	05.2009	Directive 2009/33/EC On the promotion of clean and energy-efficient road transport vehicles
European Parliament and Council Directive	06.2009	Directive 2009/30/EC amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC
Commission of the European Communities Working document	10.2009	SEC(2009)1454 Impact assessment accompanying document to the Proposal for a Regulation of the European Parliament and of the Council. Setting emission performance standards for new light commercial vehicles as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles
European Green Cars Initiative Report	2010	European Green Cars Initiative PPP. Multi-annual roadmap and long-term strategy
International Energy Agency Report	2010	The Economics of Transition in the Power Sector
International Energy Agency Handbook	2010	Energy Efficiency Governance
ACEA Guide	2010	The automobile industry. Pocket guide
Economic Commission for Europe of the United Nations Regulation	08.2010	Regulation No 49 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles. Amendments to Regulation 49 published in OJ L 103, 12.4.2008, p. 1.
Commission of the European Communities Communication	11.2010	COM(2010)656 Progress report on implementation of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles
Commission of the European Communities Communication	11.2010	COM(2010)655 Monitoring the CO2 emissions from new passenger cars in the EU: data for 2009
PWC Report	12.2010	TREN/A4/103-2/2009 Study on Urban Access Restrictions
International Energy Agency Report	2011	25 Energy Efficiency Policy recommendations
Commission of the European Communities Communication	03.2011	Roadmap for moving to a competitive low carbon economy in 2050
Commission of the European Communities Communication/White paper	03.2011	COM(2011)144 Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system
European Commission Memo		MEMO/11/238 Revision of the Energy Taxation Directive – Questions and Answers. What is the Energy Taxation Directive?
European Federation for Transport and Environment (T&E) Report	04.2011	Fuelling oil demand. What happened to fuel taxation in Europe?
European Parliament and Council Regulation	05.2011	Regulation 510/2011 Setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO_2 emissions from light-duty vehicles

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Typology	Month/ year	Extended title
International Energy Agency Report	06.2011	Clean Energy Progress Report
International Council on Clean Transportation Report	07.2011	Evaluation of parameter-based vehicle emissions targets in the EU. How regulatory design can help meet the 2020 CO_2 target
International Council on Clean Transportation Working paper	02.2012	Discrepancies between type approval and "real-world" fuel consumption and CO_2 values
International Council on Clean Transportation Report	03.2012	Estimated Cost of Emission Reduction Technologies for Light-Duty Vehicles
IARC Monograph	06.2012	Diesel and gasoline engine exhausts and some nitroarenes
CARS 21 High Level Group Report	06.2012	on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union
IARC Press release	06.2012	Diesel engine exhaust carcinogenic
European Commission Working paper	07.2012	SWD(2012)213 Impact assessment accompanying the documents Proposal for a regulation of the European Parliament and of the Council amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars and Proposal for a regulation of the European Parliament and of the Council amending Regulation (EU) No 510/2011 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new light commercial vehicles
European Federation for Transport and Environment (T&E) Report	12.2012	How clean are Europe's cars? An analysis of carmaker progress towards EU CO2 targets in 2011
International Council on Clean Transportation Report	2013	From laboratory to road. A comparison of official and "real-world" fuel consumption and CO2 values for cars in Europe and the United States
European Commission Press release	01.2013	EU launches clean fuel strategy
Transport and Environment (T&E) Report	03.2013	Mind the Gap! Why official car fuel economy figures don't match up to reality
European Commission Communication/Report	04.2013	COM(2013)214 on the application of Directive 2009/33/EC on the promotion of clean and energy efficient road transport vehicles
European Parliament and Council Decision	11.2013	Decision No 1386/2013/EU on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'
European Commission DG Environment News Alert Service Press release	12.2013	Diesel cars' climate impacts not as beneficial as believed, scientists conclude
European Climate Foundation Report	2014	Fuelling Europe's future
European Observatory on Health Systems and Policies Report	2014	Everything you always wanted to know about European Union health policies but were afraid to ask
International Energy Agency Report	2014	Energy policies of IEA countries. European Union review
International Energy Agency Report	2014	Energy, Climate Change Environment
UNECE Report	2014	Diesel engine exhaust: myths and realities
International Council on Clean Transportation Report	01.2014	EU CO2 emission standards for passenger cars and light commercial vehicles
European Parliament and Council Regulation	03.2014	Regulation (EU) No 253/2014 amending Regulation (EU) No 510/2011 to define the modalities for reaching the 2020 target to reduce CO_2 emissions from new light commercial vehicles
European Parliament and Council Regulation	03.2014	Regulation (EU) No 333/2014 amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO 2 emissions from new passenger cars
International Council on Clean Transportation White paper	10.2014	Real world exhaust emissions from modern diesel cars. A meta analysis of PEMS emissions data from EU (Euro 6) and US (Tier 2 BIN5/ULEV II) diesel passenger cars.
WHO Report	2015	Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth
ACEA Report	2015	Reducing CO2 emissions from cars and vans. Backgrounder
International Energy Agency Report	2015	Complementary measures for decarbonisation. Looking beyond pricing and regulation to motivate private businesses and state-owned enterprises
International Energy Agency Report	2015	Making the energy sector more resilient to climate change
European Commission Communication/Report	02.2015	COM(2015)70. Quality of petrol and diesel fuel used for road transport in the European Union. 12th Annual report
European Commission Communication/Strategy	02.2015	COM(2015)80 Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy
Council of the European Union Directive	04.2015	Council Directive 2015/652 Laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels
Ricardo Consulting Presentation	07.2015	History and Future of Particle Number Legislation in Europe. The Particle Measurement Programme (PMP)
International Council on Clean Transportation Report	09.2015	Transition to a global zero-emission vehicle fleet: a collaborative agenda for governments
Transport and Environment (T&E) Report	09.2015	Mind the Gap 2015. Closing the chasm between test and real-world car CO2 emissions
International Council on Clean Transportation Report	09.2015	From laboratory to road. A 2015 update of official and "real-world" fuel consumption and CO2 values for passenger cars in Europe
International Council on Clean Transportation Report	09.2015	NOx control technologies for Euro6 diesel passenger cars. Market penetration and experimental performance assessment
FEV GmbH Report	09.2015	2025 Passenger Car and Light Commercial Vehicle Powertrain Technology Analysis
Transport and Environment (T&E) Report	10.2015	Europe's tax deals for diesel
International Energy Agency Report	2016	Energy, Climate Change & Environment
Transport and Environment (T&E) Report	2016	Mind the Gap
European Environment Agency Report	2016	Explaining road transport emissions. A non-technical guide
European Commission Press release	01.2016	European Commission tightens rules for safer and cleaner cars
European Commission Report/Communication	02.2016	COM(2018)56 Quality of petrol and diesel fuel used for road transport in the European Union
Ricardo Energy & Environment Report	02.2016	Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves

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Typology	Month/ year	Extended title
European Commission Regulation	03.2016	Regulation 2016/427 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)
AECC Position paper	04.2016	Emission control technologies to meet current and future European vehicle emissions legislations
ACEA Position Paper	05.2016	Reducing CO2 emissions from passenger cars and light commercial vehicles post-2020
European Parliament and Council Communication	07.2016	COM(2016)501 A European Strategy for Low-Emission Mobility
High Level Group of Scientific Advisors/Scientific Advice Mechanism (SAM) Report	11.2016	Closing the gap between light-duty vehicle real-world CO2 emissions and laboratory testing
European Parliament and Council Directive	12.2016	Directive 2016/2284 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC
International Council on Clean Transportation Report	12.2016	NOX emissions from heavy-duty and light-duty diesel vehicles in the EU: comparison of real-world performance and current type-approval requirements
European Parliament, Directorate General for Internal Policy Report	12.2016	Nesbit, M., Fergusson, M., Colsa, A., Ohlendorf, J., Hayes, C., Paquel, K., Schweitzer, J.-P., 2016. Comparative study on the differences between the EU and US legislation on emissions in the automotive sector. Brussels, Belgium
European Environment Agency Report	2017	Air quality in Europe — 2017 report
European Court of Auditors Report	2017	EU action on energy and climate change
Ricardo consulting Report	2017	Nanoparticles: how small can you go?
International Council on Clean Transportation Policy update	01.2017	Real-driving emissions test procedure for exhaust gas pollutant emissions of cars and light commercial vehicles in Europe
European Commission Communication	05.2017	COM(2017)283 Europe on the move. An agenda for a socially fair transition towards clean, competitive and connected mobility for all.
European Commission Communication	05.2017	COM(2017)284 in accordance with Article 9 of Directive 98/70/EC relating to the quality of petrol and diesel fuels
European Commission Recommendation	05.2017	Recommendation 2017/948 on the use of fuel consumption and CO2 emission values type-approved and measured in accordance with the World Harmonised Light Vehicles Test Procedure when making information available for consumers pursuant to Directive 1999/94/EC of the European Parliament and of the Council
European Commission Working document	05.2017	SWD(2017)223 Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package
European Commission Working document	05.2017	SWD(2017)178/179 Evaluation of Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels ('Fuel Quality Directive')
European Commission Regulation	06.2017	Regulation 2017/1151 supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Commission Regulation (EC) No 692/2008
International Council on Clean Transportation Working paper	07.2017	Diesel Engines
International Council on Clean Transportation Technical brief	07.2017	Diesel Technology Developments
International Council on Clean Transportation White paper	07.2017	Shifting gears: the effects of a future decline in diesel market share on tailpipe CO_2 and NOx emissions in Europe
ACEA Press release	08.2017	Auto industry welcomes more stringent emissions tests coming into effect on 1 September
European Commission Regulation	07.2017	Commission Regulation (EU) 2017/1151 supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information (…)
ACEA Position Paper	09.2017	Post-2021 CO2 Regime for Passenger Cars
Climate action Europe Report	09.2017	Phase-out 2020. Monitoring Europe's fossil fuel subsidies
Transport and Environment (T&E) Report	09.2017	Poliscanova J., Diesel: the true (dirty) story, Transport & Environment
European Commission Impact Assessment	11.2017	SWD(2017)650/366/650/676 Impact assessment for Proposal for a Regulation of the European Parliament and of the Council setting emission performance standards for new passenger cars and for new light commercial vehicles as part of the Union's integrated approach to reduce CO2 emissions from light duty vehicles and amending Regulation (EC) No 715/2007
European Commission Communication/Regulation proposal	11.2017	COM(2017)676 Proposal for a Regulation of the European Parliament and of the Council setting emission performance standards for new passenger cars and for new light commercial vehicles as part of the Union's integrated approach to reduce CO2 emissions from light duty vehicles and amending Regulation (EC) No 715/2007
European Commission Communication	11.2017	COM(2017)675 Delivering on low-emission mobility. A European Union that protects the planet, empowers its consumers and defends its industry and workers
European Commission Communication/Directive proposal	11.2017	COM(2017)653 Proposal for a Directive amending Directive 2009/33/EU on the promotion of clean and energy-efficient road transport vehicles
Transport and Environment (T&E) Report	2018	CO2 emissions from cars: the facts
Transport and Environment (T&E) Report	2018	Cars with engines: can they ever be clean?
European Environment Agency Report	2018	Air quality in Europe — 2018 report
European Court of Auditors Report	2018	Air pollution: Our health still insufficiently protected
CONCAWE Report	2018	The Low Carbon Pathways Project. A holistic framework to explore the role of liquid fuels in future EU low-emission mobility (2050).
Ricardo Energy & Environment Report	02.2018	Assessing the impacts of selected options for regulating CO2 emissions from new passenger cars and vans after 2020

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Typology	Month/ year	Extended title
International Council on Clean Transportation Briefing	03.2018	Diesel car sales decline will have negligible impact on attainment of European CO2 emission standards
International Agency for Research on Cancer Press Release	06.2018	Diesel engine exhaust carcinogenic
European Commission Regulation	11.2018	Regulation 2018/1832 of amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) 2017/1151 for the purpose of improving the emission type approval tests and procedures for light passenger and commercial vehicles, including those for in-service conformity and real-driving emissions and introducing devices for monitoring the consumption of fuel and electric energy
ACEA Communication	11.2018	Diesel: new data proves that modern diesel cars emit low pollutant emissions on the road
European Commission Communication	11.2018	COM(2018)773 A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy
ACEA Presentation	11.2018	Modern diesel technology. Latest type-approval results for the growing fleet of RDE-compliant cars
European Environment Agency Report	2019	Air quality in Europe — 2019 report
ACEA Report	2019	ACEA Report Vehicles in use Europe 2019
European Environment Agency Report	2019	Monitoring CO2 emissions from new passenger cars and vans in 2018
Ricardo Consulting Presentation	2019	Final report to T&E of Emissions Determination from RDE Regeneration Testing
European Court of Auditors Report	02.2019	The EU's response to the "dieselgate" scandal
European Commission Report	03.2019	Transport in the European Union. Current Trends and Issues
European Parliament Communication	03.2019	P8_TA-PROV(2019)0329 Recent developments on the Dieselgate scandal European Parliament resolution of 28 March 2019 on recent developments in the 'Dieselgate' scandal (2019/2670(RSP))
European Commission Decision	04.2019	Implementation of Decision 2019/583 confirming or amending the provisional calculation of the average specific emission of CO2 and specific emissions targets for manufacturers of passenger cars for the calendar year 2017 and for certain manufacturers belonging to the Volkswagen pool for the calendar years 2014, 2015 and 2016 pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council
European Commission Decision	04.2019	(EU) Decision 2019/583 confirming or amending the provisional calculation of the average specific emission of CO2 and specific emissions targets for manufacturers of passenger cars for the calendar year 2017 and for certain manufacturers belonging to the Volkswagen pool for the calendar years 2014, 2015 and 2016 pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council
European Parliament and Council Regulation	04.2019	Regulation 2019/631 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011
Transport and Environment (T&E) White Paper	05.2019	Gasoline versus Diesel. Comparing CO2 emission levels of a modern medium size car model under laboratory and on-road testing conditions
European Parliament and Council Directive	06.2019	Directive amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles
ACEA Communication	06.2019	CO2 from new cars up for second consecutive year, raising auto industry concerns
International Council on Clean Transportation Report	09.2019	Dirty diesels grow to 51 million across EU, as carmakers still put profit before clean air
European Commission Communication	12.2019	COM(2019) 640 The European Green Deal
European Environment Agency Report	2020	Monitoring CO2 emissions from passenger cars and vans in 2019
European Commission Communication	03.2020	COM(2020) 80 Proposal for a Regulation establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law)
Transport and Environment (T&E) Report	04.2020	Road to Zero: the last EU emission standard for cars, vans, buses and trucks
ACEA Position Paper	05.2020	Principles for potential post-Euro 6 and post-Euro VI emission regulations
International Council on Clean Transportation Briefing	05.2020	The end of the road? An overview of combustion engine car phase-out announcements across Europe
International Council on Clean Transportation Briefing	08.2020	CO2 emissions from new passenger cars in Europe: Car manufacturers' performance in 2019
European Commission Press release	08.2020	Car industry: New rules on cleaner and safer cars start to apply across Europe
ACEA Report	2021	Making the transition to zero-emission mobility

Other literature: Taminau, Yvette, Molenkamp George, Svetlana Tashchilova, "The pendulum: The auto-oil programmes revisited", *Energy & Environment*, Vol. 17, No. 2 (March 2006), pp. 243–262.

Data availability

The data that has been used is confidential.

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