Technology-neutral vs Technology-specific Policies in Climate Regulation: The Case for CO_2 Emission Standards

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Executive Summary

The debate on technology neutrality versus technology specificity in environmental regulation, particularly in addressing climate change, has flared up again recently. While earlier discussions centered on decarbonizing electricity generation, primary attention has shifted to the transition to zero-emission mobility—notably focusing on the European CO_2 standards for cars. Critics of the CO_2 limits complain that they are not sufficiently technology-neutral, thereby restricting abatement options, limiting flexibility for vehicle manufacturers, and leading to unnecessary costs. In the wake of sluggish electric car sales and a sense of crisis in the automotive industry, voices are being raised calling for a postponement, relaxation, or outright repeal of CO_2 limits, advocating instead for the new European Emissions Trading System 2 to serve as the primary instrument for climate protection in the transport sector.

At first glance, technology-neutral approaches like carbon pricing seem to actually offer a superior pathway to decarbonization by allowing market participants to choose the most cost-effective methods to reduce emissions. Comprehensive carbon pricing, in theory, equalizes marginal abatement costs across all available options to mitigate GHG emissions, encouraging reductions where they are cheapest and allowing innovation to flourish without government interference. However, this theoretical superiority relies on assumptions of undistorted, perfectly working markets as well as informed and fully rational actors—conditions that are rarely met in the real world.

In reality, besides carbon markets being regionally and sectorally fragmented, market imperfections such as positive and negative externalities, information asymmetries and behavioral biases, pre-existing misaligned incentives and entrenched technological path dependencies confine the cost-effectiveness of carbon pricing alone. Imperfections in real-world markets warrant a policy mix to efficiently and effectively steer decarbonization, particularly to drive the necessary technological innovation.

Among the various market imperfections, consumers' tendency to undervalue future energy costs is a key factor underpinning the economic rationale for fuel efficiency standards. As these standards play a crucial role in lowering vehicles' specific energy consumption, they directly benefit consumers through reduced fuel costs. Additionally, by making vehicles less CO_2-intensive, the standards indirectly alleviate financial pressure on consumers in the transport sector by contributing to lower future CO_2 prices under the ETS 2. Slow regulation-induced energy efficiency progress in the vehicle fleet would cause consumers to miss out on significant savings.

Industrial policy considerations provide another argument against weakening the European CO_2 standards. As global demand for zero-emission vehicles continues to grow, maintaining and regaining technology leadership—also in EV technology—is crucial for European automakers to secure their market share in rapidly evolving markets. Stringent standards push manufacturers to innovate in electric drivetrains, battery technologies, and energy-efficient vehicle designs, thereby enhancing the international competitiveness of the European automotive industry. Consequently, watering down the standards would not only slow progress on decarbonization but also harms Europe's position in the global automotive market stifling advancements in clean technologies.

Moreover, postponing or weakening the CO_2 standards (or suspending potential penalties), particularly if done during—or even after—the final stretch toward the 2025 targets, would send a damaging signal about the reliability and credibility of European climate policy as a whole. This loss of credibility jeopardizes Europe's ability to achieve its climate targets and reduces cost-effectiveness, as firms and consumers may delay long-term beneficial investments if they distrust the stability of the regulatory framework. Strong, predictable, and consistently enforced policies are essential to maintaining confidence in climate policy, ensuring both environmental effectiveness and economic efficiency.

In consequence, there are strong reasons to maintain the CO_2 standards in full ambition and resist the temptation to weaken them. Nonetheless, thoughtful adjustments of the sector's regulatory framework may sometimes be warranted in light of new insights and evolving market developments to improve its environmental and economic performance. Striking a balance between providing reliability and maintaining environmental integrity, while allowing for meaningful reforms, is essential and requires great care. Each reform option must be judged on its capacity to provide stability for investors, strengthen the competitiveness of European manufacturers, and continue delivering both environmental and consumer benefits.

Expanding the scope of the CO_2 fleet regulation beyond vehicle characteristics directly controlled by manufacturers to include renewable fuels, such as advanced biofuels and e-fuels, does not appear justified for several reasons. Focusing on vehicle technology incentivizes manufacturers to innovate and develop more energy-efficient cars, particularly EVs. Allowing renewable fuels as compliance options could hinder this progress, as their use does not improve vehicle efficiency and may delay the development of EVs and the necessary charging infrastructure. Additionally, consumers could face financial disadvantages, suffering both from higher fuel consumption and increased fuel prices due to the higher production costs of these fuels.

Moreover, while large-scale production of first-generation biofuels competes with sectors like food production and can cause deforestation and land-use conflicts, second-generation biofuels are more sustainable but limited by feedstock availability. E-fuels require large amounts of renewable electricity, which is still in limited supply. Finally, biofuels and e-fuels are crucial for sectors like aviation and shipping, where decarbonization alternatives are still lacking, making their diversion to passenger cars inefficient and counterproductive. Hence, vehicle technology and fuel regulation should remain separate to assign clear responsibilities, encourage innovation, and save consumers money.

Expanding fleet standards even further to cover the entire vehicle lifecycle poses significant challenges, such as blurring responsibilities and the difficulty of collecting accurate global supply chain data. Combining manufacturing-related and use-phase emissions within a single metric is problematic, as it mixes fixed and usage-dependent impacts, potentially causing confusion and creating new inefficiencies. To address upstream emissions and disposal-related environmental performance, specifically dedicated policy instruments are more appropriate.

When it comes to assessing additional compliance flexibility mechanisms for car manufacturers, the principle has to be: flexibility must not become a loophole that prevents necessary emissions reductions; instead, it has to be implemented with robust safeguards to ensure steady progress toward climate goals. If regulators seek additional compliance flexibility, mechanisms such as banking and borrowing could be considered, provided they do not compromise the environmental integrity of the CO_2 fleet standards. To meet this requirement, for instance, banking and borrowing cannot be combined with the current CO_2 target trajectory, as this would lead to the generation of "windfall" emission credits. Rather, credits within a potential banking and borrowing system should only be generated relative to a continuously declining CO_2 target trajectory. Without proper safeguards like this, such flexibility mechanisms can severely harm the regulation's integrity and credibility.

To reflect the evolving nature of the automotive sector, the regulatory framework will need to undergo gradual adjustments in the future. As the share of EVs steadily rises, it will become increasingly important to expand the regulatory focus beyond only tailpipe emissions to include energy efficiency. Otherwise, there is a growing risk of partially offsetting the environmental benefits of electrification due to increasing vehicle sizes and untapped energy-saving potential. Approaches to regulate specific energy consumption should be developed soon, as they offer a way to conserve resources, reduce environmental strain, and lower costs for drivers.

In conclusion, while carbon pricing—e.g., via the EU ETS 2—remains an essential policy tool for decarbonization, a well-rounded policy mix, including targeted technology-specific interventions, is indispensable for ensuring both environmental effectiveness and economic efficiency in the transition to zero-emission mobility. Instruments such as strategic R&D support, infrastructure investments, and improved information policies are needed to address market imperfections. Within this policy mix, the EU's CO_2 standards are a key instrument, crucial for driving the innovation required to meet Europe's climate and competitiveness goals. Relaxing these standards to ease transformational pressure is like a 'sweet poison,' seemingly beneficial to the automotive industry in the short term but ultimately harmful, as it would not only undermine Europe's climate objectives but also jeopardize its long-term economic prosperity, leaving the industry vulnerable in an increasingly green global economy.

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1. Background: Europe’s climate goals, Green Deal, and Fit-for-55

Global warming is one of the greatest challenges facing mankind. As part of international agreements, in particular the Paris Climate Agreement, the European Union (EU) has committed to doing its part to combat climate change. To this end, it has set itself ambitious targets for reducing greenhouse gas (GHG) emissions. The EU has committed to cutting greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. This target is a part of the EU's nationally determined contribution (NDC) under the Paris Agreement. By 2050, The EU aims to achieve net-zero greenhouse gas emissions by 2050. The European Commission has proposed an emissions reduction target of 90% for 2040, but this has not yet been finalized.

The European Green Deal is the centrepiece on the way to achieving these goals. The European Green Deal is the EU's overarching framework for combating climate change and transforming the economy towards climate neutrality. It comprises a wide range of measures, targets and strategies aimed at reducing emissions, protecting biodiversity and promoting a sustainable economy.

The Fit for 55 package is a central component of the Green Deal and serves to achieve the shorter-term emissions reduction targets by 2030. More specifically, it is the legislative package designed to ensure the implementation of the target of reducing greenhouse gas emissions by at least 55% by 2030 (compared to 1990 levels).

The Green Deal Industrial Plan, unveiled in early 2023, should support the industrial transformation needed to achieve the objectives of the Green Deal, thereby ensuring that climate protection goes hand in hand with economic prosperity. By strategically strengthening and scaling up the EU's manufacturing capacity for clean technologies through providing a supportive environment, it aims at enhancing the EU’s industrial competitiveness, improving its energy system's resilience, and to create quality jobs.

The transport sector is a major emitter of GHG, and passenger cars contribute the most to this record. The EU’s domestic GHG emissions from transport steadily increased from 2013 until the disruption of the Covid-19 pandemic, largely due to growth in passenger transport and inland freight volumes. In 2019, transport’s share in overall domestic GHG emissions reached 28% (up from 16% in 1990 and 23% in 2005)., totalling 1.103 Mt CO_2eq. Within the sector, road transport contributes roughly three quarters of the GHG emissions; these are split again between 38% for freight transport and 62% for passenger transport. Cars alone emitted in 2019 485 Mt CO_2eq, thereby causing 13% of the EU’s total domestic GHG emissions.

Yet, the transport sector is not only a major source of GHG emissions, it is also a key pillar of the European economy. A well-functioning transportation system is a basic prerequisite for a flourishing economy based on the division of labour. In addition, the automotive industry is one of the most important economic branches and a very important employer in the EU. The automotive sector, in its broader sense, contributes 7% to European GDP and employs 13 million people (both directly and indirectly). Direct manufacturing—specifically vehicles and parts—accounts for 10% of the total European manufacturing value added and just under 2% of EU GDP, supporting 2.6 million jobs.

In light of the great importance of the sector for climate protection, several instruments of the Green Deal and the Fit for 55 package address the transport sector. These include CO_2 standards for cars, vans and trucks; expansion of the charging infrastructure for electric vehicles and promotion of the development of zero-emission drives; promoting the use of clean energy sources in shipping and air traffic, amongst others through the introduction of quotas for sustainable fuels; promotion of rail and public transport to reduce the use of private vehicles. Beyond those sector-specific measures, a second emissions trading system (ETS 2) will be introduced in 2027 that covers road transport (and some others sources such a buildings) in order to reduce emissions through CO_2 pricing. These instruments aim to reduce emissions in the transport sector by at least 90% by 2050.

Technological approaches are at the heart of (European) efforts to reduce GHG emissions in the transport sector. Given its economic importance and its major emissions contribution, the technological transformation of the car industry draws particular attention. There have been heated debates both in individual member states and at European level about the right technology policy approach and regulatory framework. An appropriate regulatory environment should help to meet the climate policy targets and at the same time economic criteria: namely cost-effectiveness in achieving the targets and securing long-term value creation, innovative strength and international competitiveness of the European vehicle industry.

One key regulatory measure that has received a great deal of political and public attention is the CO_2 fleet standards—and in particular the so-called internal combustion engine ban. They require vehicle manufacturers to reduce their new vehicle fleets' average per-km tailpipe CO_2 exhaust; they can do so by means of improving the efficiency of their internal combustion engine vehicles (ICEV) and ramping up the sales of electric vehicles (EV). The average CO_2 emissions need to go down by 15% and 55% by the year 2025 and 2030, respectively; in 2035, the new car fleet has to be CO_2-free.

The debate on CO_2 standards has flared up again recently in the wake of the European Parliament elections and the sluggish sales of e-cars in some countries. Critics of the CO_2 limits complain that they are not sufficiently technology-neutral. As a result, they would deprive citizens and companies of flexibility in their choice of climate protection efforts and thus drive up abatement costs; car manufacturers would be restricted in their entrepreneurial freedom. Ultimately, such a technology-specific regulatory framework would lead to unnecessarily high costs and could jeopardize the prosperity of the automotive industry. The argument mentioned last is often emphasized with the point that the CO_2 standards force European manufacturers to abandon the combustion engine technology, in which they are globally leading, while the transition to electric mobility is associated with economic risks due to China's control over large parts of the value chain. A climate policy approach that is as technology-neutral as possible, on the other hand, would combine short- and long-term cost efficiency with strong incentives for innovation, according to the critics' argument. Conversely, advocates of technology-specific policy instruments emphasize that progress can only be achieved quickly enough and path dependencies be overcome through targeted support measures.

This discussion paper addresses this debate from an economic perspective and is intended to serve as a stimulus for the discussions at the conference organized by SDA-Bocconi in cooperation with ECCO and Agora Verkehrswende on 16 October 2024 in Milan.

The following **Chapter 2** begins by briefly laying the conceptual foundations and outlining the arguments in favour of a policy approach that is as technology-neutral as possible. **Chapter 3** examines the "other side," it highlights the shortcomings of carbon pricing as a stand-alone technology-neutral climate policy and presents the economic rationale for technology-specific interventions in the road transport sector. **Chapter 4** reflects discussions of CO_2 pricing versus CO_2 standards from a political-economic perspective, and **Chapter 5** reports a very brief assessment of the CO_2 fleet limits in the context of European green industrial policy. **Chapter 6** delves into the debate on further developing the regulatory framework, evaluating some of the most prominent proposals for the CO_2 regulation's future, which will also be discussed further at the conference.

2. Carbon pricing as the technology-neutral silver bullet to the decarbonization challenge?

2.1 Reemergence of an economic controversy: technology-neutrality vs technology-specificity

The debate on the merits and weaknesses of technology neutrality versus technology specificity in environmental regulation – particularly in the context of efforts to address climate change – has (re-)gained prominence in recent years. The centre of these discussions has shifted from energy supply to the demand side, with a particular spotlight on the transport sector: While in the past the focus was often on the right policy approach to decarbonizing the generation of electricity, the drivetrain transition in the transport sector has recently become the focal point of the debate. Environmental and economic policy agrees in principle on the need to transition away from carbon-intensive technologies, prompting discussions on the most effective regulatory frameworks to incentivize this transition. Two competing approaches—technology neutrality and technology specificity—offer different pathways for pursuing environmental objectives.

2.2 The case for technology neutrality: What does technology neutrality mean and what are its merits?

Technology neutrality in environmental regulation is based on the idea that regulators should restrain themselves to setting clear policy objectives (such as reducing carbon emissions) without—more or less mandatorily—prescribing the specific technologies to achieve them. Instead, the choice of technologies is left to the private sector, allowing firms and consumers to leverage their decentralized knowledge of the costs and benefits of different solutions. Technology specificity , on the other hand, refers to a regulatory approach that deliberately targets particular technologies or technological pathways to achieve a policy objective. In contrast to technology-neutral regulation, technology-specific regulation either promotes or restricts the use of certain technologies. This approach may be adopted when the government or regulator has identified certain technologies as more likely to achieve long-term policy goals (e.g., decarbonization) and wishes to accelerate their adoption. The discrimination among technologies can take various forms, reaching from subsidies for preferred technologies to outright bans of less desired technologies.

According to advocates of the regulatory principle of technology neutrality, this approach fosters more efficient and innovative solutions, as market participants are typically better equipped to evaluate and select the most suitable options. By concentrating on outcomes rather than prescribing methods, technology-neutral regulation reduces the risk associated with government interference in technology selection. Advocates argue that when governments attempt to "pick winners," they may inadvertently lock in suboptimal solutions, especially when influenced by political biases or limited knowledge. A technology-neutral framework, by contrast, encourages open competition, allowing the market to identify the most cost-effective pathways for meeting environmental targets. This creates an environment that supports continuous innovation and adapts to new technological developments.

In a broader sense, technology neutrality applies not only to the selection of technologies but also to behavioral adjustments. In the transport context, consumers might, for example, choose to reduce energy consumption by adjusting their transport activity level or through modal shift instead of adopting new technologies. This flexibility broadens the range of possible solutions, allowing both technological innovation and changes in behavior to play a role in achieving environmental goals. As a result, technology-neutral policies create a more adaptable and comprehensive framework for addressing environmental challenges.

2.3 Carbon pricing as the prototypical technology-neutral policy

The realm of climate protection provides a policy instrument often considered almost prototypical for technology neutrality: carbon pricing. By internalizing the external cost of GHG emissions (not necessarily to the full extent of the actual social cost of carbon), it creates uniform incentives across all emitters and technologies without prescribing specific solutions. Through mechanisms like carbon taxes or emissions trading systems, carbon pricing allows firms and consumers to choose the least-cost ways to reduce emissions, enabling market forces to guide technological choices and behavioral adjustments. By applying the same price across emission sources, the marginal abatement costs are equalized across all emitters of GHG, fully tapping efficiency potentials and promoting cost-effective emission reductions. Hence, carbon pricing achieves emission reductions where they are most feasible. The flexibility of carbon pricing lies in its ability to provide incentives for emitters to find their own optimal methods of mitigation, whether through adopting new technologies, improving processes, or changing behaviors—and to adapt their mitigation strategies as soon as circumstances change. This would not only minimizes overall costs but also foster dynamic efficiency by encouraging ongoing innovation as firms continually seek to reduce their carbon-related expenses**.**

It should be noted here, however, that carbon pricing is also not truly technology-neutral, at least if the intended policy outcome is the reduction of global warming (with the reduction of CO_2 emissions being merely a means to that end). Other options for combating warming—such as reducing non-priced GHG, building carbon sinks, or geoengineering approaches—would not be covered. The focus on CO_2 emissions and potentially selected other greenhouse gases would already represent a limitation of the solution space, thus deviating from full technology neutrality.

2.4 Rational actors and perfect competition as requirements for superiority of technology-neutral climate policy

The theoretical superiority of carbon pricing as a technology-neutral policy for reducing GHG emissions, yet, comes with significant caveats. Its claimed cost-effectiveness relies on several highly restrictive assumptions that are rarely satisfied in real-world settings. For carbon pricing to function optimally, it presupposes a perfectly working, competitive market where firms and consumers act fully rational based on perfect information, responding efficiently to price signals by minimizing costs and maximizing utility. This idealized scenario also requires that all external costs—such as environmental damages—as well as positive externalities are fully internalized, and that market distortions such as excessive market power, pre-existing distorting regulations, or (institutional) lock-ins through vested interest are absent. Under these conditions, firms—and consumers—would reduce emissions where it is cheapest, and the most cost-effective technologies would naturally prevail across sectors. However, in reality, markets deviate significantly from this ideal. As the next section will set out in more detail, market imperfections such as various externalities, information asymmetries, consumer short-sightedness, coordination problems, and entrenched technological infrastructures distort market responses, may well lead to inefficient outcomes of climate policy that is largely confined to carbon pricing.

BOX: Technology openness is not the same as technology neutrality

To distinguish between the terms technology neutrality and technology openness, we refer to the approach in Agora Verkehrswende (2020). Technology openness refers to the required conditions within a decision field (or market) that allow different technologies to compete fairly, without distortions. While it is often confused with technology neutrality and used synonymously, the two concepts are distinct. Technology neutrality is a characteristic of regulation, meaning that the regarded regulatory framework does not favour specific technologies but lets market forces determine the solutions. However, even with technology-neutral regulation, true technology openness—i.e. fair technological competition—may not exist if the market is distorted by non-internalized externalities, path dependencies, or institutional and behavioral barriers.

A market is considered technology-open when all technological options are evaluated on the basis of their true economic costs and benefits, free from these distortions. Factors like entrenched infrastructure supporting fossil fuels, non-internalized environmental costs, or consumer biases can prevent new technologies, such as electric vehicles, from competing on a level playing field. To achieve technology openness, targeted regulatory interventions are often needed to correct these market distortions, ensuring that emerging, sustainable technologies have a fair chance to compete against established ones. This ensures that the market reflects the true long-term costs and benefits of each technology, fostering a competitive environment conducive to innovation and sustainable development. In reality, complete technology openness will never be fully achievable, but the goal of climate and economic policy should be to get as close as possible. This requires weighing the costs and risks of (technology-specific) measures aimed at increasing technology openness against the efficiency gains that such openness would bring about.

3. Market imperfections affecting vehicle technology choice

In the following, some of these market imperfections that may impair technology openness in the vehicle market and their ramifications for the cost-effectiveness of climate policy approaches are sketched out.

3.1 Positive externalities and why CO_2 pricing alone is insufficient to address them

While CO_2 pricing is an essential tool for internalizing the social cost of carbon emissions by making carbon-intensive activities more expensive, it is insufficient to address a variety of positive externalities that are inherent to the development and adoption of low-carbon technologies. These externalities, such as spillovers from R&D, learning-by-doing, learning-by-using, and network effects, represent benefits to society that the individual firm or consumer cannot fully capture. As CO_2 pricing is not well targeted to these externalities, underinvestment in innovation and slower-than-optimal diffusion of innovative, fuel-efficient technologies is a likely result.

R&D spillovers

R&D spillovers have significant implications for both the optimal fuel economy choice in general and the adoption of EV technology in particular. Due to these spillovers, the social returns from R&D typically exceed private returns, as firms cannot fully capture the benefits of their innovations. This leads to underinvestment in R&D because firms only consider their private returns, ignoring the positive externalities that spill over to other market actors. These spillovers occur when knowledge diffuses across firms, either through employee mobility, reverse engineering, or shared research networks, allowing competitors to benefit from innovations without incurring the same R&D costs. As a result, firms invest less in new technologies than would be socially optimal, leading to a slower rate of technological advancement and, specifically, suboptimal progress in fuel-efficient and EV technologies.

Although not being unique to clean technologies, this market imperfection is generally more pronounced in green innovations, where R&D returns are found to be higher – not at least due to their potential environmental and societal benefits. Carbon pricing alone, while effective at internalizing the cost of carbon emissions, is insufficient to correct this market distortion resulting from positive R&D externalities. The private sector's inability to fully capture the value of R&D spillovers means that carbon prices fail to account—from an innovator's perspective—for the broader societal gains from its innovation, resulting in less investment in long-term solutions like EVs. Hence, complementary policies such as targeted R&D subsidies and other forms of support for clean technologies can be warranted to accelerate innovation pace and achieve cost-effective emissions reductions.

Learning-by-doing spillovers

Learning-by-doing spillovers play an important role in the adoption of EVs. As manufacturers produce more EVs, their specific production costs tend to decrease due to accumulated experience and increased efficiencies—often referred to as the "learning curve." These cost reductions, however, do also not remain confined to individual firms ramping up their production levels; instead, they spill over to other manufacturers, lowering their costs as well. Competitors who adopt these technologies later can also reap the benefits without incurring the initially higher costs. As a result, early adopters could face a competitive disadvantage; at least, they cannot take full advantage of their technological avantgarde. Again, this externality leads to individual firms underinvest in EV technology roll-out because they cannot fully capture the economic benefits of their production experience. Without policy interventions that account for these learning spillovers, firms are likely to favour established technologies that are more cost-competitive in the short term due their accumulated production cost advantages. As a result, the market penetration of new, in the long-run superior technologies, like electric drivetrains, occurs more slowly than socially optimal. As with R&D externalities, carbon pricing alone, while effective at internalizing the climate costs of carbon emissions, fails to overcome this underinvestment caused by learning-by-doing spillovers as it does not address the long-term learning potentials of innovative technologies. Complementary policies—such as temporary subsidies, ZEV mandates, or CO_2 standards—can accelerate the market uptake of EVs and stimulate the socially optimal level of initial investments that lead to broader cost reductions across the industry.

Learning-by-using spillovers

The demand-side counterpart of (supply-side) learning-by-doing externalities is spillovers from learning-by-using in technology adoption: early adopters create a positive externality for other consumers in the form of valuable information regarding the availability and performance of a new technology as well as how to implement, maintain, and use it. For example, early buyers of EVs generate valuable insights into the practicality, reliability, and durability of these vehicles or knowledge about cost-effective charging routines, which benefits future buyers by reducing their uncertainty and own learning efforts. High carbon prices might encourage some consumers to switch to lower-emission technologies, but it does not compensate these early adopters for the positive externalities they create; thus, without additional incentives, the rate of adoption may be too slow to create the socially desirable momentum for wider market acceptance. In addition to information campaigns to reduce EV-related uncertainties on the consumer side, financial purchase incentives for EVs—set explicitly or implicitly via ZEV mandates or CO_2 standards— can address this market barrier.

Network effects and complementarities

CO_2 pricing is particularly inadequate in overcoming barriers related to network effects and complementarities, especially in the case of electric vehicles and their required charging infrastructure. Network effects arise when the usage value of a product, increases as more people use it. For the case of EV roll-out, so-called indirect network effects primarily occur due to the development of complementary infrastructure such as charging stations. However, without enough vehicle users, firms may be reluctant to invest in this infrastructure, creating a "chicken-and-egg" problem where both vehicle manufacturers and infrastructure providers hesitate to invest unless the other party does so first—or at least commits to invests. Conversely, the already realized network effects of the established incumbent technology, given the dense network of fuel stations, tend to solidify its dominant position.

It becomes obvious that expectations about future market developments—i.e., how the network evolves—play a crucial role for current technology choice. Besides direct subsidies for early charging infrastructure build-up and regulations—such as the European AFID—that mandate a minimum level of alternative fuels infrastructure, instruments that give direction and provide some certainty about the future EV uptake (such as ZEV mandates and CO_2 standards) foster infrastructure investments and reinforce the growth of the electric mobility ecosystem. CO_2 pricing alone does not resolve this issue, as it fails to deliver this certainty because it intentionally leaves it open by which means emissions are reduced.

Summary: Timely technology transition needs targeted innovation-oriented instruments

While CO_2 pricing, e.g. through the ETS 2 commencing operation in 2027, is essential for internalizing the climate costs of GHG emissions, it is insufficient to address the positive externalities—R&D spillovers as well as learning and network effects—critical to low-carbon technology adoption. These market imperfections imply a gap between private returns, which drive decision-making, and societal returns; by preventing firms (and consumers) from fully realizing the benefits of their innovations, they slow the diffusion of clean technologies. To overcome these barriers, targeted interventions like (temporary) subsidies, CO_2 standards, and support for infrastructure investments are economically justified to complement carbon pricing. Without such policies, the transition to a low-carbon transport system will be slower and more costly than what is socially optimal.

3.2 Non-climate externalities from fossil fuel consumption

Beyond climate damage, fossil fuel consumption leads to several further externalities. Local pollutants like nitrous oxides, sulfur dioxide, and particulate matter contribute to respiratory diseases and other health problems, while extraction and transportation can cause oil spills and habitat destruction. Energy security risk is another potential externality related to fossil fuel consumption. Economies heavily reliant on imported fossil fuels are vulnerable to price shocks and geopolitical risks, which can lead to broader economic disruptions. Therefore, governments often bear costs associated with maintaining energy security, such as (military) expenditures to protect supply routes.

If these costs are not accounted for, they create a competitive disadvantage for fuel-efficient vehicles and EVs. This justifies, on the one hand, policy interventions beyond carbon pricing. On the other hand, some of these externalities can be addressed similarly to carbon pricing through a surcharge on fuel prices. This applies, for instance, to energy security externalities. However, addressing damages from air pollutant emissions is more complicated because these are often highly location-dependent, affecting citizens differently based on their proximity to emission sources. Furthermore, many of these pollutants are produced and cause harm irrespective of whether fossil or renewable fuels are combusted. Hence, policies that support drivetrain technologies free of tailpipe emissions prove effective in reducing these harms.

3.3 Institutional barriers to clean technology market development

This section highlights a selection of institutional and market environment barriers that constrain the effectiveness of carbon pricing in driving the most cost-efficient technological transformation in the car market. These barriers include information asymmetries, coordination problems, capital market imperfections, misaligned taxation incentives, and risk-averse firm behavior. Each of these issues distorts market dynamics and can hinder the optimal response to carbon pricing signals, underscoring the need for complementary policies to support a transition to more fuel-efficient vehicles.

Adverse selection: Lemons in the new vehicle market?

The concept of adverse selection helps explain how information asymmetries distort markets, including those for fuel-efficient technologies and EVs, and cause inefficiencies. If consumers lack adequate and reliable information about important product characteristics, such as about a vehicle's fuel economy and energy cost, there is no appropriate willingness to pay for them; as a result, the corresponding characteristic is both insufficiently demanded and supplied. In the new vehicle market in many countries, manufacturers and retailers must disclose fuel economy, expected fuel costs, and CO_2 emissions, but these figures often differ from actual on-road performance. Despite this inaccuracy, consumers can still make relative comparisons, reducing the impact of adverse selection.
In the used vehicle market, however, there are often no equivalent disclosure requirements. Without reliable fuel economy data, buyers undervalue fuel-efficient used cars, creating an adverse selection problem. This undervaluation feeds back into the new vehicle market via the resale value, reducing the willingness of first-hand buyers to pay for fuel-efficient technologies if they cannot capitalize on higher future resale prices of efficient vehicles.

Of course, the most straightforward approach to address this issue is improving the accuracy and transparency of fuel economy and energy cost data in both new and used vehicle markets. Mandatory disclosure of fuel consumption and better testing procedures can mitigate adverse selection. Given remaining limitations to information policies, CO_2 standards can still also make a contribution to overcoming the negative impacts of adverse selection by mandating continuous improvements in the vehicle fleets' energy efficiency.

Distortions from company car taxation

In several countries, a major share of the entire new vehicle market is purchased as company cars; they account for almost 60 percent of all new car sales in the EU. Preferential taxation regulations for company cars (e.g., deductibility of fuel costs, lump-sum benefit-in-kind taxation) can possibly constitute another barrier, unfolding multiple adverse effects on the energy efficiency and overall environmental performance of the overall vehicle fleet.

Since the purchase costs and the fuel expenses for company cars are tax-deductible, companies tend to acquire larger, more powerful, and consequently more fuel-consuming cars than private buyers. While fuel expenses for private vehicle usage are regularly billed on the company and tax-deductible, employees often pay a lump-sum tax for private usage based on the car's retail price. This creates a twofold disincentive for energy-saving technologies when employees can choose their company car: they may well disregard fuel costs in their decision process rationale and forego available fuel-saving technologies that would increase the retail price of the company car (e.g., electric drivetrain) and thus their tax payments. In consequence, employees will mainly demand vehicle attributes other than energy efficiency. This is underscored by vehicle registration data for the EU that shows a positive correlation between vehicle size and the share of registrations as company cars in the respective vehicle class. Furthermore, these characteristics of company cars may shape consumers' preferences in the private vehicle market. If the features of company cars (regarding size, engine power, luxury amenities etc.) become the reference point, consumers could develop an aversion towards "downgrading" in these vehicle properties and be reluctant to purchase smaller, more fuel-efficient vehicles for private purposes. Finally, as company cars are regularly resold after a few years; they largely determine the fuel economy levels available in the used car market some years down the road.

While carbon pricing does not remedy the underlying misaligned tax incentives, neither do fuel efficiency standards address the root cause; they can only mitigate the adverse effects to some degree. Revising company car taxation schemes, as already done in the meantime in several countries, would—quite obviously—be a more effective (and socially more just) solution, aligning incentives with environmental goals and promoting the adoption innovative technologies.

Capital market imperfections

Many new vehicle purchases are financed through loans, and the higher upfront costs of EVs can complicate financing. While better energy efficiency of EVs reduces future energy and CO_2 costs, thereby improving a borrower's ability to repay, lenders may not account for this due to information asymmetries and transaction costs. Assessing the reduced credit risk associated with fuel-efficient vehicles may not be cost-effective for lenders, and uncertainties regarding the resale value of EVs add further risk. Higher financing costs for EVs may result, slowing their adoption. Even though carbon pricing makes fuel more expensive, consumers might still opt for cheaper, less efficient vehicles due to financing constraints. Debt aversion presents another potential challenge, where consumers are hesitant to take out loans even when the expected fuel savings would more than cover the loan costs. This reluctance can also possibly deter buyers from opting for fuel-efficient EVs, particularly when conventional vehicles do not require financing. Solutions like loan guarantees or supported (social) leasing programs may be more effective in addressing these financing challenges than CO_2 standards, however. Overall, while capital market imperfections can affect EV adoption, they do not seem to be a major obstacle in the current market context.

On the supply side of the vehicle market, capital market imperfections are thought to potentially hinder capital-intensive R&D activities as well as the realization of increasing returns (e.g., learning effects, economies of scale) in the production of fuel-efficient vehicles through setting up large-scale manufacturing facilities and penetration pricing. Yet, the question arises why – particularly for investments in clean vehicles – the capital market would not provide the required funds (for expectedly beneficial investment projects) at adequate conditions. For high-stake industrial investments, the (transaction) costs for evaluating the investment project's financial prospects are small (relative to the lending/investment volume) compared to consumer credits. It may well be true that credibility and commitment issues concerning the government's pursuit of long-term climate goals heighten lending and investment risks, thereby reducing the willingness to provide funds or leading to higher demanded interest rates. Is this the case, CO_2 standards can help to drive down demanded interest for electrification investment projects through increasing the investment's expected profitability and reducing its risks. However, this would not reflect a genuine deficiency in the capital market but rather a political shortcoming (see chapter 4); hence, it remains ambiguous whether capital market imperfections systemically inhibit the development and deployment of innovative vehicle technologies.

Market power as a potential innovation obstacle

Market power in the vehicle industry can also present a barrier to the adoption of EVs and fuel efficiency technologies if dominant manufacturers, particularly those invested in conventional vehicles, may delay introducing innovative—electric—-drivetrains to protect their existing market and avoid network effects that benefit new competitors. Moreover, large incumbents with lobbying power can try to hinder smaller, innovative firms from entering the market via regulatory channels.

Firms with considerable market power may also engage in price discrimination by offering different levels of fuel efficiency and technological innovation based on consumers' willingness to pay. This can lead to suboptimal fleet-wide fuel efficiency, particularly disadvantaging lower-income consumers, as fuel-efficient technologies are withheld or underprovided for certain market segments (particularly smaller and cheaper cars). Notwithstanding, a certain—moderate—market concentration also has positive impacts on innovation activities. Whereas consolidated monopolistic as well as an atomistic market structure normally hinder innovation, some degree of market concentration is regularly most fruitful with respect to dynamic product development processes. This is because competitive incentives remain, while barriers related to spillovers as well as to insufficient funding of R&D and for pre-financing increasing returns of learning-by-doing are less of an issue; with some degree of market concentration, both effects strike a balance.

The strategic behaviors of (too) powerful firms, such as potentially withholding technologies or price discrimination, is not addressed by carbon pricing. Fuel efficiency standards—although minimum standards more than fleet-average standards—can be more effective in advancing efficiency progress, as they limit the ability of firms to strategically offer suboptimal fuel efficiency across different market segments. However, minimum standards can reduce manufacturers' flexibility and may also slow innovation to some degree by not incentivizing improvements beyond the minimum requirements.

Coordination challenges

Transitioning to new technologies, such as electric drivetrains, often requires significant coordination due to the interdependence and complementarity of various inputs and the realization of increasing returns (learning and network effects, economies of scale). New technologies become cost-effective sooner when produced at scale, but vehicle manufacturers and suppliers of complementary products may hesitate to make the necessary early investments due to high upfront costs and uncertain market developments. In particular, penetration pricing—where early sales are priced below production costs to accelerate market adoption—can be crucial for realizing increasing returns but may pose financial risks. Individual manufacturers may lack the resources or willingness to bear these risks alone. Horizontal coordination, such as joint ventures for establishing shared platforms or R&D collaboration, can help distribute the financial burden and accelerate the rollout of new vehicle technologies. Fuel efficiency standards can provide limited support by signalling the need for joint advancement of innovative technologies.

Vertical coordination is equally important, especially in synchronizing the rollout of EVs with the development of complementary infrastructure, such as charging stations. Without such—not necessarily formal—coordination, manufacturers may delay commercialization, and energy suppliers may hesitate to build infrastructure due to uncertain demand. Public interventions, including infrastructure subsidies as well as direct or indirect mandates for minimum EV market shares via quotas or CO_2 standards, can help resolve this "chicken-and-egg" problem.

Beyond technological challenges, the transition faces institutional barriers. The existing "techno-institutional complex," which includes entrenched interests, legal frameworks, and educational systems favouring incumbent technologies, can resist change. Overcoming these barriers requires broad, coordinated efforts, including adjustments to educational curricula, redirecting public R&D funds, and reforming legal frameworks.

Risk-averse firm behavior and managerial incentives

Established firms, also vehicle manufacturers, often demonstrate risk-averse behavior that impedes the adoption of innovative, fuel-efficient technologies such as electric drivetrains. This reluctance to take entrepreneurial risks can be linked to principal-agent problems, where managers prioritize short-term financial outcomes over long-term investments in R&D or production capacities for innovative technologies. Managers, who are evaluated on annual performance metrics such as annual profit, stock prices or dividends, may avoid investing in new technologies that offer substantial long-term benefits but entail short-term risks or uncertain returns. This behavior is consistent with managerial economics research, which highlights how misaligned incentives lead managers to favour immediate gains over long-term corporate value maximization.

Uncertainty surrounding future carbon pricing and regulatory frameworks further exacerbates this aversion to take short-term risks. The unpredictability of emissions trading schemes or potential changes in environmental policy can deter firms from committing to green technologies, as the potential for future returns becomes more uncertain. Without clear signals from regulators, firms may fear that investments in fuel-efficient technologies, particularly EVs, could become unprofitable, further disincentivizing long-term planning. Moreover, if uncertainties also arise from a lack of policy credibility, and future policies are influenced by current firm behavior, there may even be a risk of strategic investment reluctance (see Chapter 4).

Governments can address these barriers by ensuring regulatory certainty through reliable emissions standards with clear near-term compliance requirements and ambitious long-term targets—in addition to stable carbon pricing mechanisms. Research suggests that when firms are given clear regulatory targets, they are more likely to invest in innovation, as the risks associated with such investments are reduced. Thereby, and through other measures like mandating the disclosure of carbon risks, regulation can help align managerial decision-making with the firm’s financial objectives and long-term environmental goals that benefit society as a whole.

Summary

A number of institutional, structural, and regulatory factors in the vehicle market—e.g., information asymmetries, coordination problems, and misaligned incentives—can act as barriers that prevent consumers and manufacturers from responding optimally to CO_2 price signals. As a result, complementary policies—such as improved information disclosure, financial support for initial infrastructure investments, taxation reform—are necessary to ensure that climate policy leads to more efficient outcomes in the vehicle market. For CO_2 standards, there is also a rationale for them to serve as a pillar in the policy mix, acting as a robust guardrail that guides the necessary technological transformation.

3.4 Behavioral barriers to EV and fuel economy adoption

The transition to more fuel-efficient vehicles, particularly EVs, is hampered not only by misaligned incentives, institutional obstacles, coordination challenges and different kinds of externalities, but also by behavioral barriers. Traditional economic models assume that consumers make rational decisions by fully accounting for both the upfront costs and the long-term operational costs associated with innovative, fuel-efficient technologies and their conventional alternatives. Under this assumption, carbon pricing mechanisms—such as taxes or cap-and-trade systems—should effectively incentivize consumers to purchase cleaner, more efficient vehicles by increasing the cost of fuel and enhancing the financial benefits of fuel efficiency.

However, empirical evidence suggests that real-world consumer behavior often deviates from this rational model due to various behavioral anomalies. These cognitive biases and decision-making heuristics tend to lead consumers to undervalue future energy cost savings and overemphasize immediate costs and benefits. As a result, carbon pricing alone is insufficient to drive optimal adoption rates of fuel-efficient vehicles and technologies, even if they are generally available. This chapter highlights some key behavioral anomalies affecting vehicle purchase decisions. It also briefly discusses why additional policy interventions are necessary to address these behavioral barriers.

Loss Aversion, endowment effects, and status quo bias

Loss aversion, a concept from behavioral economics and an empirically well-documented phenomenon, describes individuals' tendency to perceive losses as more painful than equivalent gains are pleasurable. This amplifies the decision weight of perceived losses, often implying endowment effects or a status quo bias. Individuals assign higher value to items they mentally or physically own, making them reluctant to part with these items without substantial compensation. These biases can deter consumers from adopting fuel-efficient vehicles like EVs. In the financial dimension of vehicle purchases, higher upfront costs may be perceived as immediate and significant losses (when compared to the price of a conventional car), outweighing potential long-term savings from lower operating costs, even when carbon pricing increases the relative cost of less efficient options.

In the hedonic dimension, loss aversion heavily influences consumers' preferences for sensory and performance-related vehicle attributes, such as comfort, size, or acceleration, as well as range and refuelling or recharging time. If consumers are accustomed to certain vehicle features due to prior ownership or use of a company car—resulting in emotional attachment and mental endowment—they tend to be reluctant to forgo these attributes, perceiving their absence as a loss. This makes the less tangible benefit of fuel efficiency less appealing. Consequently, consumers often prioritize hedonic attributes over fuel economy in vehicle purchase decisions, again posing challenges to the adoption of EVs. These challenges are further exacerbated when concerns like range anxiety or limited charging infrastructure are prominently discussed in public discourse.

It is important to emphasize that the disproportionate decision weight placed on foregone vehicle traits (or on the higher purchase price), as described here, does not correspond to an equally strong impact on the actual utility experienced over the vehicle's lifetime. Then, the exaggerated focus on "lost attributes" leads to inefficient decisions.

Narrow bracketing, money fungibility, and mental accounting

Narrow bracketing is a cognitive bias where individuals make decisions in isolated mental "accounts," without considering the broader context or long-term implications. This often manifests as mental accounting, where people categorize and treat money differently based on arbitrary classifications, rather than viewing all money as fungible and interchangeable.

In vehicle purchasing, consumers frequently focus narrowly on the purchase price, treating it as a separate mental account from future operating costs like fuel expenses. This segmentation can lead them to undervalue the long-term savings from fuel efficient EVs because they do not integrate these savings into their overall financial evaluation of the vehicle. Carbon pricing increases future fuel costs but does not affect the vehicle's purchase price. If consumers are narrowly focusing on the upfront cost and treating different expenditures as non-fungible, the higher future fuel expenses of a combustion vehicle do not (appropriately) influence their immediate purchase decisions in a way that best caters their own financial interest.

Salience effects

Salience effects occur when individuals disproportionately focus on information or attributes that are more prominent or easier to observe (or to experience) when making a decision, often neglecting less noticeable but important factors. In car purchases, highly salient attributes include the sticker price, brand reputation, design, and performance features such as horsepower and acceleration. Conversely, long-term fuel savings and environmental impacts are less visible and receive less attention.

Consumers may then find it easier to compare vehicles based on these immediate, salient features rather than complex calculations of future energy cost savings. The cognitive effort required to assess lifetime costs is higher, and without salient cues, consumers may default to simpler criteria. Although carbon pricing increases fuel costs gradually, it does not substantially enhance the immediate visibility of fuel efficiency benefits at the time of purchase. As a result, consumers may continue to prioritize salient features over fuel economy, even when fuel costs are higher. Again, EV adoption particularly suffers from this bias. A Well-designed efficiency label can improve the salience of energy efficiency properties and their cost implications, thereby attenuating this bias, but they still remain less tangible than other vehicle characteristics.

Discounting anomalies and short-sighted decision-making

Discounting anomalies can significantly influence vehicle purchase decisions, particularly regarding fuel economy. Unlike standard discounted utility theory, which assumes stable and rational discount rates, consumers may exhibit quasi-hyperbolic discounting. Hyperbolic discounting describes the tendency of individuals to prefer smaller, immediate rewards over larger, delayed ones, with the preference for immediacy diminishing over longer time horizons. In contrast to the exponential discounting assumed in traditional economic models—where the discount rate remains constant—hyperbolic discounting leads to time-inconsistent preferences. When buying a car, the immediate gratification from a lower purchase price or desirable vehicle features (particularly status-conveying features) then outweigh the benefits of long-term savings on fuel expenses. Besides higher monetary upfront cost, switching to an EV can go along with higher non-financial effort—e.g., installing a wallbox, finding public charging stations or securing a suitable electricity supplier. These immediate non-monetary costs, amplified by immediacy effects, further impede market uptake.

The framing of fuel cost savings also plays a crucial role in intertemporal decision-making. If the returns from a fuel efficiency investment are seen as small, dispersed, and uncertain-in-magnitude gains spread over several years, they will be heavily discounted in consumers' decision-making processes, reducing their perceived utility. In contrast, aggregating these savings over the vehicle’s expected lifetime or ownership period and framing them as avoided losses (that would be incurred with a conventional car due its higher fuel costs) could potentially increase their decision weight; obligations to present energy cost implications in such a manner—through efficiency labels, for instance—may help to this end. Also, leasing options or installment payments might to some degree mitigate the immediacy effect working against efficiency investments. Still, discounting anomalies tend to hinder the adoption of efficiency technologies, even if it is economically rational over the vehicle's lifetime.

Bounded rationality and rational inattention

In addition to the behavioral biases depicted above that lead to distorted, non-rational decisions, in principle rational decision-making—albeit constraint by cognitive limitations—can also result in underinvestment in EVs and fuel-efficiency technologies. The inherent complexity of vehicle purchase decisions exacerbates the issue of bounded rationality. Buying a car involves weighing multiple attributes—i.a., performance, comfort, fuel economy, and price—often under uncertainty about future fuel prices, maintenance costs, and resale values. Given this multitude of factors, many consumers find it cognitively taxing to calculate the total cost of ownership for the available vehicle options.

As a result, consumers may rely on simplified decision-making heuristics. To conserve cognitive resources, they often focus disproportionately on immediate costs, such as the vehicle's sticker price, while neglecting long-term operational savings. This behavior is closely tied to the concept of rational inattention, which occurs when consumers deliberately ignore or simplify complex information that requires significant cognitive effort to process. Even when the future fuel savings and reduced carbon costs of an energy-efficient vehicle model could prove economically beneficial, gathering and analyzing information on these benefits may be perceived as too costly in terms of time and mental energy. Additionally, consumers may lack sufficiently credible, accurate information about fuel efficiency and may not fully trust the available data, leading to scepticism about potential savings. In consequence, consumers may rationally choose to overlook the long-term advantages of fuel-efficient EVs, leading to a systematic undervaluation of these technologies.

Summary

While carbon pricing is a fundamental tool for internalizing the external costs of GHG emissions, its environmental and cost-effectiveness is limited by the behavioral anomalies outlined above. As empirically evidenced, consumers' decision-making processes do not always respond to price signals in the rational manner assumed by traditional economic models. Behavioral biases and bounded rationality can lead to systematic underinvestment in fuel-efficient technologies and suboptimal adoption rates of EVs, even if such investments are economically advantageous over the long term. These issues necessitate a multifaceted policy approach that combines carbon pricing with other interventions to address behavioral barriers in a targeted manner.

The highlighted behavioral barriers essentially come down to the same effect: they result in consumers being deterred by high upfront costs and failing to adequately value long-term benefits. CO_2 standards can then make a contribution towards overcoming these barriers. The CO_2 standards cause manufacturers to set up an internal feebate (or bonus-malus-scheme), penalizing CO_2-intensive vehicles and subsidizing low-emission vehicles such as EVs, in order to manage their sales so that they comply with the regulation. Thereby, CO_2 standards can better link the vehicle choice with immediate financial consequences, making future operating costs more tangible in the present decision context. Moreover, through mandating a certain progress in overall energy efficiency of the new vehicle fleet, the potential negative impact of behavioral anomalies is mitigated.

3.5 Conclusion: the need for a policy mix to overcome barriers to EV adoption

In theory, carbon pricing creates cost-effective incentives for reducing emissions, but in real-world contexts, it cannot fully overcome obstacles to the development and adoption of low-carbon technologies. Thus, even with carbon pricing in place, the adoption of EVs and fuel-efficiency technologies faces numerous barriers that hinder their market penetration. These barriers limit the environmental and cost-effectiveness of a climate policy that relies mostly or exclusively on carbon pricing. Although it is clear that the ideal conditions required to make carbon pricing effective as a stand-alone policy are not met in reality, this does not provide an economic justification for technology-specific interventions of any kind. On the one hand, technology-specific instruments must always be tailored to the nature and extent of the specific market imperfections present. On the other hand, such interventions can themselves create new inefficiencies, particularly when there are informational deficits on the part of the regulator, or when interventions are influenced by political or lobbying interests. Ultimately, a careful trade-off is always necessary between the potential efficiency gains and the risks associated with the various potential interventions.

Although its ability to drive the adoption of EVs and fuel-efficient technologies is constrained by various market imperfections, it is important to emphasize that carbon pricing is still crucial for internalizing the—in their magnitude not exactly known—social cost of carbon emissions. Given the diverse nature of barriers laid out above, a well-balanced policy mix is essential to complement carbon pricing. Beyond a CO_2 pricing scheme, this mix should include targeted R&D support, initial public financial backing for charging infrastructure, improved transparency through information obligations, and reforms to the fiscal framework. Such a combination of policies can more effectively address the structural and behavioral obstacles that prevent widespread EV adoption and drive the transformation of the car market in due pace.

The role of CO_2 standards in the policy mix

In this policy mix, CO_2 standards play a critical role. Over more than ten years, they have established themselves as a credible and reliable policy instrument, offering planning certainty to vehicle manufacturers and suppliers of complementary goods like charging infrastructure. By setting clear, long-term emissions targets, the European CO_2 standards reduce investment risks and provide the stability needed for firms to commit to large-scale transitions, such as building EV production lines or expanding charging networks. Eventually, through pushing manufacturers to meet strict emission targets, the standards indirectly mandate a certain share of EVs in the new vehicle market.

To comply with the standards, firms will regularly set up implicit feebate systems, subsidizing the sale of EVs while penalizing CO_2-intensive vehicles. This internal cross-subsidization makes EVs more affordable, countering the upfront cost barriers that deter consumers from purchasing them. In doing so, CO_2 standards help accelerate the adoption of technologies that generate positive externalities.

In conclusion, while CO_2 standards are not a silver bullet, neither is carbon pricing. Both instruments play complementary roles in the climate policy framework. Rather than debating the abandonment of CO_2 standards in favour of carbon pricing alone, targeted reforms should be pursued to enhance their effectiveness and better leverage synergies. These reforms must retain the core structure of the European CO_2 standards, however, to avoid undermining their credibility (see next chapter). The predictability they provide is crucial for investment and planning, and weakening that certainty could jeopardize the long-term success of the EV transition.

On the difficulty to find the right carbon price in the presence of market imperfections

While an indispensable part of the policy mix, it remains true that no single CO_2 price can simultaneously achieve optimal long-term technology adoption and short-term behavioral adjustments if market imperfections—such as spillovers, consumer biases, or misaligned incentives—undermine the effectiveness of carbon pricing. In a world without market imperfections, the solution would be straightforward: setting the carbon price at the marginal damage cost or marginal abatement cost (as per the Baumol-Oates price-quantity framework) would yield the cost-minimal abatement mix. However, in the presence of market imperfections, particularly behavioral biases, there is no first-best CO_2 price capable of delivering optimal GHG mitigation. Without complementary instruments, market imperfections necessitate high carbon prices to promote low-carbon technology adoption—for instance, to encourage consumers to purchase electric vehicles. However, such elevated prices could also induce excessive short-term behavioral responses, such as reducing travel beyond economically efficient levels. Thus, a carbon price high enough to stimulate technological innovation might overshoot what is necessary to influence less-distorted behaviors, leading to suboptimal outcomes—and vice versa. If consumers undervalue fuel economy and carbon pricing were the only available policy instrument, a third-best carbon price would have to strike a balance between incentivizing demand for fuel efficiency and containing welfare losses due to distorted driving decisions. Even with complementary policies in place to address market imperfections, it remains nearly impossible to set a carbon price that simultaneously incentivizes optimal investment and travel behavior decisions. For example, in the presence of heterogeneity in how consumers undervalue future fuel costs, a carefully calibrated compromise must be found to balance—inevitably remaining—distortions between technology adoption and mobility behavior.

4. Political-economic considerations

This chapter briefly explores the discussion around a potential relaxation of CO_2 fleet limits as well as the relationship between carbon pricing and efficiency regulation from a political-economic angle.

4.1 Challenge from time-inconsistent regulatory behavior

One of the fundamental challenges for environmentally and cost-effective climate regulation is time-inconsistent decision-making by regulators. This occurs when regulators, often under economic or political pressures, retrospectively revise previously established environmental policies. Such ex-post changes can undermine the credibility and long-term effectiveness of climate policies, jeopardizing the achievement of climate goals when measures designed to reduce GHG emissions are diluted or postponed.

Pressure from firms that have not taken timely action to meet emission reduction targets is a primary reason for time-inconsistent behavior among regulators. When firms fall short of their targets—or are about to do so--due to inadequate early-on mitigation efforts, they face the prospect of high costs from penalties or the need for rapid, drastic emissions reductions. To avoid these costs, firms exert considerable lobbying pressure on regulators to relax the rules. This pressure intensifies the longer companies delay action, as the eventual costs become higher and the incentives to seek regulatory easing grow stronger.

4.2 Credibility as a key success factor

When firms anticipate the possibility of regulatory adjustments in response to slow environmental progress, they may even strategically withhold investments in improved fuel efficiency. This approach—requiring some degree of market and political power—them to save on abatement costs in the short term, while avoiding the potentially high costs and disruptions associated with a delayed but rapid ramp-up of efforts if targets are actually relaxed. Such strategic non-compliance, or ratchet effects (in a broader sense), undermine the achievement of climate policy goals and could also result in even greater costs in the more distant future. This is particularly true if the industry is forced to scramble to eventually meet inevitable long-term GHG mitigation obligations.

Therefore, credibility plays a crucial role in the environmental and cost-effectiveness of climate policies. When regulations are credible from the beginning—that is, when stakeholders believe that ex-post changes (particularly with regard to overall stringency) will not occur—firms and consumers are more likely to take timely action to reduce emissions. This proactive behavior reduces the risk of actual ex-post regulatory changes that result from insufficient mitigation efforts at the outset. Conveying credibility ex-ante through firm and predictable policies helps minimize the likelihood of time inconsistency by encouraging early compliance and investment in low-emission technologies. Conversely, without credibility, firms and consumers may delay or avoid making necessary investments, undermining the entire policy framework. Importantly, the capability of conveying credibility of (new) regulations hinges on the regulator's record of past behavior.

4.3 Vulnerability to time-inconsistency: regulatory approaches vs. market-based instruments

In the current debate over postponing or relaxing European CO_2 standards, some economists argue that regulatory approaches like CO_2 standards and command-and-control measures in general are more vulnerable to time-inconsistent behavior by regulators than market-based pricing instruments. These critics claim that regulations are less apt to accommodate unexpected developments and that their inflexibility—potentially causing sharp increases in abatement costs in the event of slower-than-anticipated progress—makes them more susceptible to political pressure. Moreover, the large and diffuse group of affected emitters would make coordinated efforts to weaken climate policy measures more difficult in the case of carbon pricing instruments. Thus, they deem pricing instruments such as the ETS 2 preferable not only because of their alleged greater cost-effectiveness resulting from mitigation flexibility but also due to their perceived resilience to political interference, providing stronger long-term emission reduction incentives. Some even suggest abandoning fleet CO_2 standards entirely in favour of managing transportation sector emissions exclusively through the ETS 2.

Yet, the threat of time inconsistency stemming from a lack of (ex-ante) credibility is inherent in both regulatory and market-based environmental policies. There are reasons to argue that carbon pricing mechanisms may actually be equally or even more vulnerable to time inconsistency. Despite an emission cap set several years in advance and price stabilizing measures like the Market Stability Reserve in the ETS 2, political pressure to ex-post weaken the emissions cap can arise if carbon prices increase sharply. Businesses, citizens, and political parties may lobby for the cap to be loosened, undermining the effectiveness and efficiency of the trading system.

Moreover, carbon pricing also faces a "double" time-inconsistency challenge. Private decision-makers—particularly private consumers but also firms—often exhibit time-inconsistent myopic behavior, focusing on short-term cost savings over long-term benefits (see chapter 3.3). For example, in the absence of instruments complementing carbon pricing, consumers might opt for cheaper, less energy-efficient vehicles, while firms delay investing in cleaner technologies. This myopia results in higher short-term emissions and a lock-in to CO_2-intensive technologies, which exacerbates the scarcity of emissions allowances and drives up their prices.. As prices rise, political pressure to ease the emissions cap grows. In this way, the time inconsistency of private actors compounds that of political regulators, potentially creating a reinforcing cycle that finally weakens climate policy.

Thus, the argument that carbon pricing mechanisms are inherently more politically credible and less vulnerable to time-inconsistent interventions than regulatory approaches like CO_2 standards appears flawed. Neither carbon pricing nor fleet standards are immune to political (adverse) interference; of course, some interventions can be economically well-justified in light of new information. Eventually, the effectiveness and efficiency of any climate policy depend critically on its detailed design and the ability to maintain commitment over time.

Incidentally, it should be noted that fleet CO_2 standards are not purely command-and-control instruments. They actually possess characteristics of market-based quantity instruments. By regulating the specific CO_2 emissions at the manufacturer level, they allow flexibility through averaging within a firm's fleet; moreover, the pooling option provides (limited) tradability with other manufacturers.

4.4 Time consistency through a well-balanced policy mix

A well-balanced policy mix emerges as a solution to the credibility and time-consistency problem. Thoughtful coordination of the instruments is essential to harness synergies and minimize adverse interference to the greatest extent possible. Such a mix not only addresses the various market imperfections described above more effectively than a rather mono-instrumental policy approach, leverage the specific strengths of each instrument—it also enhances the resilience and credibility in climate policy. A diversified set of policy instruments provides multiple levers to achieve emissions reductions, increasing the likelihood of meeting environmental targets. Additionally, a policy mix implicitly creates a "safety net" that can cushion the impact of weakening of a single policy instrument weakened due to political pressure or other factors; other instruments can—at least partially—compensate to widely maintain overall environmental effectiveness as well as incentives for the required technological transition.

4.5 Conclusion

In conclusion, the issue of time inconsistency and lacking credibility poses a significant threat to the effectiveness of both regulatory and market-based climate policy instruments. Maintaining credibility is essential for the success of climate policies. Only firm, predictable regulations enable businesses and consumers to make the necessary investments to meet climate targets in a cost-effective manner. The pressure to dilute or delay measures—driven by both political and private interests—must be countered by strong policy commitments, robust institutional frameworks, and mechanisms capable of withstanding lobbying pressures. Moreover, the instrumental design should aim to eliminate incentives for strategic non-compliance and mitigate the ratchet effect. For CO_2 standards, for example, having more frequent interim targets rather than increasing stringency in 5-year increments could contribute to this end (see Chapter 6.4).

A well-crafted policy mix that combines regulatory measures with market-based instruments offers the most resilient and effective approach. By leveraging the strengths of different instruments and providing a safety net against the weakening of any single policy, such a mix enhances both the environmental and economic outcomes of climate policy.

Importantly, regulators should always bear in mind that past decisions undermining the credibility of an instrument will also affect the credibility of future instruments and targets. For example, any weakening or postponement of fleet emission targets for 2025 will inevitably damage the credibility of future vehicle CO_2 targets as well as other climate policy instruments.

5. CO_2 standards and the EU's green industrial policy

Beyond advancing environmental sustainability in the transport sector, its CO_2 standards are a cornerstone of the EU's green industrial policy. The Green Deal Industrial Plan, introduced by the European Commission in early 2023, aims to enhance the competitiveness of Europe's net-zero industry and accelerate the transition to climate neutrality. A key initiative under this plan, the Net-Zero Industry Act, seeks to scale up the EU's manufacturing capacity for technologies essential to the clean energy transition. Together, these initiatives should align climate protection with economic growth, strengthen the EU's industrial base, create quality jobs, and support energy independence.

Within this context, CO_2 standards are instrumental in driving the global competitiveness of the European car industry. That European car manufacturers have long been at the forefront of green automotive technology development was also due to the standards imposed by the EU. By mandating reductions of their vehicles' specific CO_2 emissions, these regulations compel manufacturers to innovate, invest in R&D, and adopt advanced technologies. This accelerates technological progress in electric drivetrains, battery technology, and also lightweight materials; the CO_2 standards contribute to reducing per-unit costs through economies of scale and learning curve effects, making European cars more price-competitive internationally. In a rapidly evolving automotive market, these investments enable European manufacturers to maintain competitive advantages or help regain them where they have been lost in recent years. As global demand shifts toward low-emission vehicles, the EU industry must leverage and expand its green technology expertise to sustain international market share. Compliance with stringent CO_2 standards in the domestic market also positions European carmakers to succeed in export markets with strict regulations, such as China and California, where the demand for advanced low-emission technologies continues to grow.

Conversely, the European automotive industry risks being permanently left behind in key future markets if swift and substantial investments are not made in advanced clean technologies. In some of these areas, international competitors have already overtaken European manufacturers. To prevent the gap from widening and to instead initiate a successful catch-up, the European industry cannot afford any further delays in the transformation. Weakening now the fleet CO_2 standards in any form (including compliance postponement or suspension of penalty payments) would slow down the transformational momentum and innovation pace, and create uncertainty about the seriousness and ambition of the EU's transition to a cleaner passenger car fleet. Decelerating the transition to EVs and a retreat to internal combustion engines would increasingly block access to important export markets, elevating risks of losing market shares to competitors from regions with stricter regulations. Ultimately, this could undermine the economic significance and value creation of the European automotive industry, threatening jobs and even the survival of entire companies.

Beyond vehicle technology, CO_2 standards also drive investment in complementary products and supporting infrastructure, whose demand could also stagnate without regulatory pressure to produce EVs, stifling the broader transition to a low-carbon economy. This would reduce Europe's general attractiveness as a hub for future green automotive technologies.

Abandoning CO_2 standards would not only harm the global competitiveness of Europe's automotive industry, it would also directly jeopardize its ability to meet its climate targets under the Paris agreement. The transport sector is a key contributor to GHG emissions in Europe, and without strict CO_2 standards, emissions from this sector would not decline quickly enough to meet the EU's climate goals. This shortfall would place additional pressure on other (industrial) sectors of the economy to compensate, potentially leading to costly and economically damaging interventions; thus, even other sectors in the economy may suffer from decelerated progress in the automotive industry.

In conclusion, relaxing the CO_2 standards would not only undermine Europe's climate goals but also put its economic prosperity at jeopardy, leaving the automotive industry vulnerable in an increasingly green global economy.

6. Critical assessment of options for further development of the regulatory framework

While there are strong economic arguments for CO_2 fleet limits to remain a key pillar of the transport sector's climate policy mix, this does not preclude discussions about further developing the regulatory framework in the future. Several proposals for adjustments have already been made in the past. This chapter critically assesses some of the options that have emerged in the debate and may be discussed during the review process of the CO_2 standards.

6.1 Accounting for renewable fuels

During the most recent reform of the European CO_2 emission standards, proposals were made to recognize the use of renewable fuels—specifically renewable fuels of non-biological origin or e-fuels—for compliance with CO_2 limits. Eventually, the European Commission was tasked with developing a proposal to implement such a provision; as of now, the implementation is still pending. In addition, there are also recurring voices calling for the inclusion of biofuels. However, several arguments caution against integrating vehicle technology regulation with fuel regulation. It is preferable to keep them separate to ensure effective decarbonization, foster innovation, and avoid the risks associated with overreliance on biofuels and renewable electricity-based synthetic fuels.

By setting limits on tailpipe emissions, CO_2 standards force manufacturers to develop and market more energy-efficient vehicles. This can be achieved either by reducing the specific CO_2 emissions of ICE vehicles, which also lowers their fuel consumption, or by increasing the share of EVs in their fleets, which are inherently more energy-efficient than ICE vehicles. Thus, CO_2 standards contribute to cutting motorists' energy costs—providing the standards' consumer side rationale.

This impact of CO_2 standards is especially beneficial when institutional and behavioral barriers, as discussed in prior sections, prevent vehicle buyers from making cost-effective fuel efficiency decisions entirely on their own. In such cases, mandating better fuel efficiency through regulatory standards can reduce consumers' total cost of vehicle ownership and generate overall economic gains. Allowing biofuels or e-fuels to be used as a compliance option would negate this benefit, however. Switching from fossil to renewable fuels does not improve a vehicle's fuel efficiency, and these fuels are likely to remain scarce and expensive for the foreseeable future.

Focusing regulatory efforts on tailpipe emissions ensures that manufacturers are incentivized to invest in the most innovative drivetrain technologies, in particular EVs which produce zero tailpipe emissions. Only the development and production scaling of innovative technologies, such as those in EVs, carries significant positive externalities that benefit not only the automotive sector but also the broader economy: Beyond spillovers within the automotive industry, EVs continue to drive advancements in battery technology or renewable energy integration. Permitting biofuels and e-fuels to count toward vehicle CO_2 standards would also slow down the build-up of the necessary infrastructure for EVs, reducing positive network effects.

In contrast to EVs, ICE vehicles, even when powered by e-fuels, are technologically widely mature and offer little potential for further innovation. The development of ICE drivetrains has reached a plateau, meaning they generate no significant positive externalities in terms of technological spillovers or infrastructure development. In consequence, allowing compliance via alternative fuels might well hamper reaping economically beneficial external effects through a delay in the transition to electric vehicles.

In addition to delaying electrification, there is considerable uncertainty surrounding the future availability and scalability of biofuels and e-fuels. Producing these fuels at scale is resource-intensive, often requiring vast amounts of land and water, or renewable electricity. Large-scale production of first-generation biofuels, in particular, competes with other critical sectors, such as food and fodder production, and can result in deforestation, biodiversity loss, and land-use conflicts unless stringent sustainability criteria are strictly enforced. While second-generation biofuels (e.g., based on waste cooking oil) are more sustainable, their production is inherently limited by the availability of sustainable feedstocks. Similarly, e-fuels are produced through an energy-intensive process that consumes large amounts of renewable electricity, which is still in limited supply and unlikely to soon meet the growing demand from multiple sectors. Moreover, an additional challenge can arise from securing sustainable carbon dioxide, which is needed in the production of liquid e-fuels, as direct air capture may be more costly than expected and biogenic CO_2, though suitable, is often decentralized and scarce, requiring substantial logistical efforts. Thus, referring to sourcing e-fuels from favourable locations outside of Europe (i.e., sweet spot regions for renewable electricity) cannot fully resolve these issues, as those countries also have to decarbonize their own economies, leading to a need for renewable electricity as well as renewable hydrogen and hydrocarbons.

Even if there is confidence in the long-term prospects of these fuels, the uncertainty about their scalability in the mid-term poses a significant risk to the regulation. If manufacturers adopt an e-fuels strategy and these fuels are eventually not available at the required amounts, the regulation will become very costly or—more likely—be rendered ineffective. In the first case, manufacturers would have to abruptly ramp-up their EV production and rapidly cut their sales of ICE vehicles to still comply with the CO_2 standards. In the second case, the pressure to weaken the regulation is becoming too great to resist, leading to missed climate goals in the transport sector and potentially undermining the broader objectives of decarbonization.

Nonetheless, it is economically advisable to promote the development and production of renewable synthetic fuels. While ICE vehicles that use alternative fuels barely deliver substantial positive externalities, advancing renewables-based synthetic fuels can generate significant positive externalities, such as technological spillovers during their R&D and particularly during their production phases. Yet, the arising of these benefits are largely independent of the sector in which the fuels are used. Thus, when considering the specific implementation of policies to realize such positive externalities, it is prudent to already take into account where these fuels will provide the greatest long-term environmental and economic benefits. Within the transport sector, e-fuels, as well as biofuels, are most valuable in aviation and shipping, where alternatives to liquid fuels are widely not feasible in the foreseeable future. Therefore, the development of production capacities for renewable liquid fuels should from the outset focus on these areas where long-term demand is expected due to the lack of viable technological alternatives. The incentives arising from their consideration in the CO_2 standards could hinder this alignment. If they result in the use of renewable liquid fuels—beyond by-products—in large quantities in the passenger car sector, where electric vehicles are a viable and more efficient alternative, this would constitute an inefficient allocation of resources.

Finally, another important reason for maintaining separate regulations for vehicle technology and fuels is the regulatory clarity and the clear allocation of responsibilities. Automakers, who are subject to CO_2 standards, have direct control only over the tailpipe emissions of their vehicles, which they can influence through technological improvements and managing their sales mix. Therefore, it makes sense to address and hold accountable fuel suppliers as well as transport operators for scaling up e-fuels. Instruments such as the EU's Renewable Energy Directive, ReFuel Aviation, and FuelEU Maritime are suitable tools to incentivize fuel production without interfering with vehicle regulations.

6.2 Expanding the regulatory scope to the entire vehicle life cycle

The climate impact of road vehicles is not restricted to their use phase. GHG emissions occur over the entire life cycle of the cars, from resource mining and material production to the manufacture and finally the end-of-life phase. For combustion vehicles, the total life cycle GHG footprint is clearly dominated by usage phase emissions. This is also true for electric vehicles with the current electricity mix (and even more so with further growing shares of renewable electricity), but here concerns have been raised about the emissions during the manufacture of the vehicles, more specifically about the battery production. Hence, there are proponents who argue to even further widen the scope of the regulation to also include these emissions—that is, in favour of taking a vehicle's entire lifecycle emissions as the regulation's metric. However, this would be problematic for a number of reasons.

First, given globalized value chains, the data requirements of a comprehensive life cycle approach for entire vehicles, which are among the most complex consumer products, are huge. Information is needed on a large number of processes linked to resource extraction, materials processing, and manufacturing. The same holds true for disposal and recycling patterns as well as for processes in primary production that are substituted by recycled materials. In addition, the required information is very dynamic as all actors involved in the system are continuously working on process improvements and adapting their supply chains; this applies in particular to the supply chain for EVs, which is less mature compared to that of ICE vehicles. Given that this information can hardly be obtained accurately in the short and medium term, the applied data would have to rely—at least partially—on default values. Using defaults, however, does not set proper incentives for CO_2-reducing innovations, and legal disputes would be likely. Also, the question arises whether the lifecycle GHG metric should distinguish those GHG emissions that are already subjected to other climate policy measures from unregulated emissions. Even if the quality of data could be improved over time, its gathering for the entire vehicle life cycle would still remain challenging, involving large effort as well as establishing credible MRV systems overseas.

Second, the manufacturing (including all upstream production processes) as well as the end-of-life emissions of vehicles have a different character from the emissions during their operation, similar to the difference between fixed and variable costs in a purchase decision. The latter are widely variable depending on the usage, whereas the former are independent of the usage patterns. A combined metric can potentially cause economically and environmentally adverse distortions—particularly if the metric is also used for consumer information purposes. For instance, depending on the expected mileage over the vehicle's lifetime, it may be reasonable to accept slightly higher emissions during production (e.g., for lightweight materials) in order to achieve lower emissions during use; for passenger cars with high mileage, this could potentially reduce lifecycle emissions per kilometer driven, whereas this would not apply to vehicles with comparatively low mileage. A metric combining fixed and variable emissions may struggle to address such tradeoffs.

Third, according to the behavioral barriers outlined above, consumers tend to insufficiently factor in future (energy) costs when making vehicle purchase decisions. This is one of the key rationales for imposing CO_2 standards, or fuel economy regulations in general, because they can counteract this tendency and thus create net welfare gains. This undervaluation applies to the use phase of the vehicles but not to their production stage as manufacturing-related carbon costs (via CO_2 pricing) and energy costs have already accrued at the time of the vehicle purchase decision. Manufacturers incorporate them in vehicle retail prices, so they are highly salient and thus not underestimated or undervalued by vehicle buyers. Hence, fleet standards for light-duty vehicles—as well as obligatory efficiency information (e.g., fuel economy labels)—should focus on cost determinants beyond the purchase price in order to help consumers making better decisions in terms of total cost of ownership—that is, efficiency during operation. Disposal-related costs (or revenues) and emissions also occur in the future, but they do not justify the same concern with regards to the undervaluation rationale as (a) their absolute magnitude is relatively small and (b) the costs are often not borne by the consumer.

Notwithstanding, improving the lifecycle environmental performance of new vehicles is a highly important issue to be taken care of, particularly with regard to the batteries. However, to address upstream emissions and disposal-related environmental impacts, specifically dedicated policy instruments like the EU's Renewable Energy Directive, the New Batteries Regulation or the Corporate Sustainability Due Diligence Directive are more appropriate. Replacing the current CO_2 standards by a life cycle regulation will neither help consumers nor does it guarantee better environmental yields.

6.3 Regulating energy consumption of EVs

Reducing the limit value for the average CO_2 emissions of the newly registered cars acts as a catalyst for electrification. The electrification rate of new cars will need to reach substantial levels by 2025 and is likely to exceed half of new registrations by 2030. However, as this trend becomes ever more prominent, the regulation becomes less relevant as a driver for energy efficiency to the fleet as a whole, since a shrinking share of vehicles actually emit CO_2. The current CO_2 standards do not set any (implicit) efficiency targets for EVs as they do not emit any tailpipe CO_2, irrespective of their energy consumption. In this situation, market forces could lead to a fleet of increasingly large, heavy and energy-consuming (electric) vehicles; and this trend may also extend to the remaining ICE fleet if electrification progresses faster than anticipated, thereby reducing the pressure to lower the fuel consumption of combustion vehicles. This would run counter not only to the original intentions of the legislation, which also had energy efficiency implicitly in mind, but also to the spirit of the EU Green Deal and to the general sense that unfettered growth in resource consumption is incompatible with any notion of sustainable development.

Thus, with the ever-rising market share of EVs, it is no longer feasible to continue ignoring their energy consumption in regulatory frameworks. For one, the behavioral barriers to energy efficiency that were outlined above also apply to EVs. Thus, leaving EVs' energy consumption unregulated means potential financial savings for motorists remain untapped. For another, electricity generation causes environmental harm, which could be mitigated with less energy-consuming EVs; this also applies—albeit to a lesser extent—to renewable electricity, which is not entirely free of environmental issues and relies on scarce raw materials. Furthermore, with growing demand across multiple sectors, renewable electricity will remain a valuable and limited resource for years to come, warranting its judicious use. Finally, a fleet of large and heavy (electric) vehicles poses health risks (e.g., more microplastic pollution from tire wear), occupies more urban space, and increases traffic safety risks.

The current format of the legislation was initially designed for a fleet dominated by combustion cars. As time and electrification progress, it is advisable to prepare provisions in the regulatory framework for the transport sector, aimed at specifically regulating the energy efficiency of road vehicles rather than focussing only on their tailpipe CO_2 emissions. As emphasized in Chapter 4, reliability and credibility are central pillars of a successful long-term climate policy. Striking a balance between these principles and the need for regulatory adjustments to improve precision and adequacy—while also limiting regulatory complexity—is always a challenging task. Different forms of 'dual regulation' that may achieve such a balance should be carefully considered and evaluated; in the U.S., for example, specific fuel consumption and CO_2 emissions are regulated separately, yet in a coordinated manner. This approach could retain the current tailpipe CO_2 standards to ensure planning security while introducing complementary measures better targeted towards energy efficiency. The latter could involve technology-specific minimum efficiency targets or apply to the entire fleet.

As the regulatory gap primarily concerns EVs, a relatively quick remedy would be to introduce a new, additional efficiency regulation for electric vehicles only, while maintaining the existing legislation in its current format, at least during a transitional phase, to uphold the principle of regulatory reliability. The additional regulation could use the specific final energy consumption per kilometer driven as a metric; it would act as an implicit cap on electricity costs for motorists and safeguard against a continuous growth in size and performance of electric cars, which would otherwise undermine the environmental advantages of introducing these vehicles.

Yet, consumers' tendency to undervalue future fuel costs provides an economic rationale for introducing a separate CO_2 (or energy consumption) target for the ICE vehicle fleet. As previously mentioned, efficiency incentives for combustion engine vehicles would largely vanish under a fleetwide CO_2 target if car fleet electrification progresses quickly (faster than anticipated). A specific CO_2 limit for combustion vehicles could serve as a short-term stopgap to ensure a minimum efficiency level, given the close correlation between their CO_2 emissions and energy consumption.

At a later stage, the regulation could be fully shifted to using final energy consumption as the metric for all new vehicles. This approach would create efficiency incentives for the remaining ICE vehicles, as well as for plug-in hybrids and fully electric vehicles. While incentivizing the tapping of efficiency potentials for all drivetrains, there would still be strong incentives to advance the market uptake of EVs due to their inherently lower final energy consumption.

While different approaches are conceivable to better address the energy efficiency challenges arising from an increasingly technologically heterogeneous fleet, it is crucial to act promptly to prevent unsustainable developments in the vehicle market. To enable timely implementation of potential further developments to the sector's regulatory framework in this regard, possibly in the wake of upcoming reviews of the CO2 standards, the EU Commission should immediately begin laying the groundwork by commissioning necessary studies and initiating stakeholder consultations.

6.4 Banking and borrowing to provide compliance flexibility

As the 2025 CO_2 target for vehicle fleets approaches, concerns are mounting within the industry that some manufacturers may struggle to meet their obligations, which would lead to penalties. There has been discussion recently around postponing the 2025 target by two years, suspending penalty payments, or generally weakening the standards to provide manufacturers with more time or 'compliance flexibility.' However, rather than improving flexibility in compliance, such proposals would effectively dilute the standards. Postponing the target (as well as suspending penalties, which in practice means the same) would have significant negative effects. Higher-emitting vehicles sold during the two-year extension would remain on the road for an average of 15 years, resulting in higher cumulative emissions, which ultimately matter for climate protection. Additionally, this delay would mean consumers miss out on energy cost savings and could face rising CO_2 prices in the newly introduced ETS 2 due to a higher allowance demand from the transport sector.

Banking and borrowing mechanisms could actually provide compliance flexibility while—if well-designed—ensuring or potentially even enhancing the environmental integrity of the regulations. These mechanisms, already implemented in some regulations such as the U.S. Corporate Average Fuel Economy (CAFE) and GHG standards, allow manufacturers to manage compliance over time. Banking permits manufacturers to generate credits by exceeding their CO_2 emission or fuel efficiency targets in a given year, which can be "banked" and used in future years when compliance may be more challenging. Borrowing, on the other hand, allows manufacturers to meet current obligations by borrowing credits from future compliance periods, with the understanding that they must make up for the shortfall in later years. To further increase compliance flexibility, credits can be made tradable across manufacturers—again as in the U.S.

Upon careful design, banking and borrowing could enable manufacturers to comply more cost-effectively with their CO_2 abatement obligations by providing additional temporal flexibility, while still ensuring full-scale long-term emissions reductions. However, it is critical to adopt a structure for the CO_2 targets that secures these mechanisms do not undermine the environmental integrity of the standards. Currently, new CO_2 targets in the European fleet standards take effect in five-year intervals, remaining unchanged during the interim periods. This stepwise tightening of fleet limits would almost inevitably result in manufacturers generating excess credits in the years leading up to a new target year. This is because manufacturers cannot adjust their emissions "overnight"—that is, from a year preceding a target year to the target year itself—to match the extent of the target value changes occurring with the step to the next five-year interval. Although manufacturers tend to reduce their emissions disproportionately as they approach a year with a stricter target, the reduction must begin earlier due to product and production planning requirements. Thus, with a flat CO_2 target trajectory in interim years, the normal market ramp-up scenario risks allowing manufacturers to accumulate substantial 'windfall credits ' in the years before a new target takes effect. These credits could then be used to emit more in years immediately following a tightening of the CO_2 target, thereby increasing cumulative emissions (compared to the regulatory status quo) and delaying necessary climate action.

To avoid these risks, a gradual—rather than stepwise—tightening of CO_2 targets, such as a linear pathway between key target years, is required . This would prevent the generation of 'windfall credits,' ensure a smoother transition, and promote continuous improvement without the 'last-minute' rush to compliance seen in past years or the postponement of substantial electrification efforts until the last possible moment. By prompting vehicle-specific emissions to decrease more steadily over time, this design would lower cumulative emissions and deliver more immediate environmental benefits.

With borrowing, there remains a risk that firms may fail to meet their future obligations, for instance, if technological advancements or needed shifts in the sales mix do not materialize as expected by manufacturers; this risk is further exacerbated if the current management focuses too heavily on short-term profits or relies excessively on a late catch-up strategy. In such cases, high penalties may be due, possibly generating substantial pressure for a subsequent weakening of the system. To maintain the credibility of a banking and borrowing system, particularly in the case of borrowing, safeguards should be implemented. Manufacturers borrowing credits could be required to deposit a portion of the potential penalty (in the event of failing to offset the borrowed credits) as security, increasing the likelihood that they meet their future obligations. Furthermore, the amount of borrowing permitted could be capped to prevent over-reliance on future reductions.

To conclude, in principle, banking and borrowing mechanisms allow manufacturers to align their strategies over time, reduce costs, and encourage early investments in cleaner technologies, all while achieving a steady reduction in vehicle emissions. Securing a system that is credible, well-regulated, and effectively monitored—one that includes robust safeguards for environmental integrity and avoids creating loopholes—is essential to preventing potential pitfalls. A key safeguard is coupling these mechanisms with a trajectory of continuously tightening CO_2 targets. By rewarding manufacturers for early mitigation actions, such a system could ideally also help counteract ratchet effects (see Chapter 4) and provide additional energy cost savings to consumers by leveraging efficiency potentials that might otherwise remain untapped during interim years due to non-binding targets. What is clear, however, is that target shortfalls in the coming year cannot be compensated for by overcompliance along a flat CO_2 target trajectory without risking severe damage to the system's credibility and environmental integrity.

6.5 Conclusion: Keep focus on vehicle technology, avoid potential loopholes

As with almost any regulation, this also holds true for the CO_2 standards: In light of new insight and dynamic market developments, regulators must strike a difficult balance between—on the one hand—regulatory evolution and—on the other hand—providing stability and planning certainty for investors as well as maintaining credibility. Thus, as the automotive sector transitions towards zero-emission mobility, vehicle regulation must evolve thoughtfully to remain reliable and maintain their effectiveness, thereby continuing to deliver both environmental and consumer benefits, and to strengthen the competitiveness of European manufacturers.

Consequently, regulating CO_2 and energy efficiency during vehicle operation should remain the primary focus of the standards, as it respects the direct responsibilities of manufacturers, who have full control only over a vehicle's fuel efficiency. This approach also aligns best with consumer interests by promoting energy savings. Including fuels in the regulatory scope or considering a vehicle's entire lifecycle emissions complicates accountability and makes the regulation significantly more complex. Additionally, scarce (sustainable) biofuels and renewable electricity-based synthetic fuels may be diverted from sectors where they are most needed, such as aviation and shipping.

As electrification progresses, focusing solely on tailpipe CO_2 emissions is no longer sufficient, as a growing share of the fleet will remain unregulated, and significant efficiency improvements could be foregone. Future regulations must place greater emphasis on energy consumption, the options to do so need to be assessed now.

If regulators seek greater compliance flexibility and consider mechanisms such as banking and borrowing, it is crucial that they are designed without loopholes that could undermine the regulation's ambition. For example, with banking and borrowing, it is essential to adjust the CO_2 target structure to ensure a continuous rather than stepwise tightening of standards to prevent the creation of “windfall” credits. A robust design must safeguard environmental integrity and deliver efficiency gains for consumers.

7. Final remarks

Maintaining robust CO_2 standards is essential for achieving Europe's climate goals and ensuring the global competitiveness of its automotive industry. Carbon pricing alone cannot adequately address the market imperfections and barriers that slow the adoption of clean technologies. CO_2 standards—integrated within a broader policy mix—ensure that manufacturers continue to innovate, improve vehicle efficiency, and can compete in the rapidly growing zero-emission vehicle market. Weakening these standards would harm Europe's prospects for technological leadership, slow decarbonization, and increase long-term costs for consumers and businesses alike.

While it is crucial to uphold the overall stringency of the standards to preserve credibility, planning certainty, and environmental integrity, the shift towards electrification may warrant careful adjustments—particularly to regulate the energy efficiency of electric vehicles in the future. Flexibility mechanisms that provide manufacturers with additional compliance options, such as banking and borrowing, must be implemented very thoughtfully to avoid diluting environmental goals. Expanding the scope of the fleet standards to include fuels or the entire vehicle life cycle would blur responsibilities and complicate regulation, potentially stifling innovation and delaying decarbonization in other key sectors like aviation and shipping.

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