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Balancing Environmental, Fiscal, and Welfare Impacts of Transportation Decarbonization in France

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ABSTRACT: France has taken a leadership role in global mitigation and made significant progress towards reducing greenhouse gas emissions, but further efforts will be needed to meet domestic mitigation targets. Accelerating emissions reductions from road transportation will be a key part of this strategy, as they account for nearly one-third of national emissions. At the same time, with the shift to more lightly taxed electric vehicles over the next decade, fiscal revenue from the sector is projected to decline and externalities, such as congestion, to worsen. Building on existing policies, a comprehensive reform that combines revenue-neutral continuous feebate schemes with a gradual introduction of road user and congestion charges could support mitigation targets, while maintaining revenue and regulating externalities. This paper discusses administratively feasible options to introduce such policies as well as key welfare and distributional considerations.

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WORKING PAPERS

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Contents

Executive Summary	3
Introduction	4
Overview of Transportation Emissions and Policies	5
Transportation Sector Emissions and Targets	5
Key Considerations Related to Road Transportation Policies	8
Road Transportation Sector Policies	9
Evaluation of Existing Policies	13
The Impact of Potential Reform Measures	19
Quantitative Assessment of Policy Reform Options	19
Policy Conclusions	27
Conclusion	
Annex I. Model Description	
Annex II. Additional Charts	
References	37
BOXES	
1. Estimating Welfare Impacts and Efficient Tax Levels	17
FIGURES	
1. Historical Emissions by Sector and Composition of Transportation Emissions	6
2. Comparison of the Transportation Sector Across EU Countries	7
3. Road Fuel and Electricity Taxes Across EU Countries in 2023	10
4. Vehicle Bonus/Malus Schedules	11
5. Projected Emissions Under Existing Policies	15
6: Revenue and Welfare Impact of Existing Policies	16
7. Distributional Impacts of Existing Road Transportation Fuel Taxes	17
8. Illustration of Welfare Effects	17
9. Environmental Costs Relative to Existing Policy Costs, per Unit of Energy	
10. Total Cost of Ownership and Energy Prices by Policy and Vehicle Type in 2030	21
11. Emissions and EV Sales Impact of Evaluated Policies	23
12. Revenue Impact of Evaluated Policies in 2030	24
13. Welfare Impact of Evaluated Policies in 2030, Relative to Existing Policies	25
14. Road Transportation Electricity Demand in 2030 Under Various Policies	27
15. Feebates Across Countries and Linear Feebate	
16. Pre-Tax Retail Prices for Electric and Internal Combustion Vehicles	35
17. Revenue from Different Policy Options Over Time	
18. Road User Charge Sensitivity	

TABLES

1. Decarbonization Policies Applied to Road Transportation Activities in France	12
2. Analyzed Reform Options	19
3. Historical Data Used in the Model	
4. Total Cost of Ownership Parameters	

Executive Summary

France is a leader in global mitigation initiatives, with ambitious domestic decarbonization targets of its own. France has been an integral part of multilateral frameworks, including the Conference of the Parties (COP), Green Climate Fund, and various other initiatives. It is committed to reducing emissions by 50 percent below 1990 levels by 2030, followed by a decline to net zero by 2050.

Accelerating emissions reductions in road transportation sector is needed to achieve domestic mitigation targets. Transportation is the largest source of emissions at around one-third of the total, and emissions reductions in the sector have historically lagged that of other sectors. However, declining electric vehicle (EVs) costs create the possibility to reverse this trend and achieve emissions targets with limited welfare impacts.

Despite a strong existing policy package, emissions from road transportation are projected to exceed France's sectoral target. At the same time, as driving shifts to relatively lightly taxed electricity, fiscal revenues generated by the sector are projected to fall from 1.4 to 0.9 percent of GDP and the economic cost of driving-related externalities, like congestion, worsen by half a percent of GDP by 2030.

This paper contributes to road transportation policy in France by assessing current policies and reform options on environmental, fiscal, and welfare criteria. The analysis uses a standardized framework that incorporates all major French and EU-policies to help understand interactions across the complex suite of overlapping policies. There are several policy-relevant findings.

Changes to existing policies can strengthen fiscal and decarbonization incentives but are unlikely to reduce emissions to targeted levels nor stem the loss in revenue. For example, transitioning from the current bonus/malus system to a revenue-neutral feebate, and applying a separate feebate to heavy goods vehicles, would save 0.1 percent of GDP in revenue and reduce emissions by a couple percentage points. Gradually increasing domestic carbon pricing and using it as a price floor for the forthcoming EU ETS II provides similar revenue and environmental benefits. Increased EV subsidies are also analyzed in the paper and reduce emissions, but with significant budgetary and economic efficiency costs. This highlights that subsidies should focus on promoting equity and distributional objectives, building off existing means-tested components.

Over time, road user and congestion charges should complement the fine-tuning of existing incentives. This would require introducing charges according to distance driven and levying an extra fee when driving on congested roads. This paper shows that when charges are calibrated to the size of externalities, emissions align with the sectoral carbon budget, road transportation revenue increases to 2.5 percent of GDP, and environmental benefits net of economic costs reach 0.4 percent of GDP. To enhance mitigation incentives and address distributional concerns, distance-based charges could be coupled with higher fuel taxes, feebates, and robust revenue recycling, including investment in public transportation and cash transfers targeted at those most impacted by policy reform. The paper also outlines potential administrative mechanisms, such annual circulation fees varying with distance driven and based on odometer readings, that could be introduced as the authorities build the required administrative capacity to implement more targeted road user charges and perform the analysis needed to better understand distributional impacts.

Introduction

France has set ambitious decarbonization targets and is a leader in global climate initiatives. Limiting global warming to 1.5 to 2°C, the central goal of the Paris Agreement, requires cutting global emissions of carbon dioxide and other greenhouse gases by 50 and 25 percent, respectively, by 2030 compared to 2019 levels, followed by a rapid decline to near net zero emissions by the middle of the century (IPCC 2022). Compatible with global goals, France is committed to a 50 percent reduction in emissions below 1990s levels by 2030 and achieving net zero emissions by 2050. To align policies with mitigation objectives, the country sets five-year carbon budgets at the sector level. Coordination of climate analysis and policies is led by the General Secretariat for Ecological Planning (SGPE), which sits under the Prime Minister. Additionally, France has been an integral part of the Conference of the Parties (COP) multilateral framework and plays a key role in contributing to climate financing for developing countries, including the Green Climate Fund.

Achieving France's climate goals requires accelerating emission reductions in the transportation sector, which is the largest emitting sector by a significant margin. The transportation sector's share of national emissions has grown considerable over the past decades, from one-quarter of total emissions to the current level of around one-third, due to sectoral emissions falling more slowly than that of most other sectors. Cost declines in electric vehicles provide an opportunity to quicken emissions reductions at, potentially, low economic, social, and fiscal costs. There are several existing and planned policies to incentivize reductions in transportation emissions, including electric vehicle purchase subsidies, EU passenger vehicle standards, fuel taxes, and public transportation investment. However, analysis in this paper and by others (SGPE 2023, EEA 2023) find that existing policies are not sufficient to achieve the targeted emissions reductions.¹

Continuing efforts to promote a well-studied and designed policy mix can help strike the right balance across various climate, fiscal and social objectives. Understanding the interactions across the complex suite of EU-wide and domestic decarbonization policies is needed to assess the fiscal, social, and emissions impacts, including the extent to which policies alter driving-related costs like congestion and traffic accidents. The fiscal impacts of the transition have macroeconomic significance—the transportation sector currently raises nearly 1.5 percent of GDP in revenue but this is projected to fall as vehicles transition from relatively high taxed oil products to electricity. There are also equity considerations, including differential impacts of the transition and public policies on rural vs. urban households and across the income distribution. The various objectives, such as fiscal sustainable and emissions reductions, may be competing at times and a standardized framework to assess trade-offs can help inform policy design, which is partly the objective of this paper.

This paper reviews existing road transportation policies and evaluates several reform options on environmental, fiscal, and social objectives. The first section provides relevant background on road transportation emissions and key decarbonization policies, and evaluates the impact of existing policies on emissions, fiscal revenue, and welfare. It finds that existing policies are welfare improving but additional effort is needed to achieve mitigation targets and avoid a structural decline in fiscal revenue from the sector. The second section assesses various reform options, such as road user and congestion charges and adjustments to the bonus/malus system, that could help balance fiscal, environmental, and social objectives. A key result is that transitioning to road user charges and increasing incentives for heavy goods vehicles can be welfare improving, given high

¹ Achieving decarbonization at the lowest cost requires an economy-wide carbon price, as well as other policies to address market failures, and then the market determining the sectoral contribution to emissions reductions. This paper takes as given that France uses a sectoral approach and focuses on policies to achieve road transportation targets.

environmental benefits, and help achieve climate and fiscal objectives. The paper finishes with a brief conclusion.

Overview of Transportation Emissions and Policies

One-third of national emissions in France come from the transportation sector, with around 90 percent of sectoral emissions from road fuels. Road transportation emissions per capita and electric vehicle sales are similar to the average of other advanced EU countries. Sectoral emissions are projected to decline by 20 percent from 2023 to 2030 due to existing policies and declining EV costs, but still exceed the carbon budget and provisional SGPE 2023 target by 15 percent. The benefits of less congestion, pollution, and other externalities are expected to more than offset the economic costs, although the latter increases as passenger vehicle emissions-standards tighten—moreover, there is generally overcharging for pollution costs and underpricing of driving-related externalities across vehicle types. Fiscal revenue from road transport is projected to decline by 0.5 percent of GDP by 2030 as driving shifts to relatively lightly taxed electricity.

Transportation Sector Emissions and Targets

The road transportation sector is of particular importance given its large and growing share in national emissions. Transportation is the largest emitting sector at 32 percent of total emissions in 2022 and 130 million tons (Mt) of CO2 equivalent. Despite a modest decline in sectoral emissions since peaking in 2004, transportation's share of national emissions has increased from 26 percent in 2000 due to other sectors' achieving larger emissions cuts.² Reductions in emissions are due to improvements in fuel efficiency, which have more than offset increases in driving distances (GoF 2023b). The latest provisional carbon budget, published in the draft 2023 National Energy and Climate Plan (GoF 2023a), implies a sharp reduction in emissions. The carbon budget for 2024-2029 and 2029-2033 are 23 and 36 percent below 2023 levels, respectively, and imply a much larger annual emissions reduction than the 0.4 percent achieved since 2000.³

Transportation sector emissions are highly concentrated in road transportation (90 percent). Passenger vehicles emit 68 Mt (17 percent of national emissions), heavy goods vehicles 30 Mt (7 percent), light commercial vehicles 20 Mt (5 percent), and buses 3 Mt (1 percent) (Figure 1). The remainder of sectoral emissions are split between domestic aviation, rail, and maritime. Passenger vehicles and light commercial vehicle emissions remain below pre-COVID levels while emissions from heavy good transport have returned to pre-COVID levels.

² International maritime and aviation are not included in domestic emissions under the UNFCCC accounting system and, thus, excluding from this analysis.

³ The current transportation sector annual carbon budget is set at 113 million tons of CO2 equivalent (Mt) for years 2024-2029 and 94 Mt for 2029-2033 but subject to a revision that is provisionally set at 100 and 83 Mt for 2024-2028 and 2029-2033, respectively. The revision will be finalized as part of the SNBC 3.



France's road transportation emissions per capita are roughly on par with other EU countries. Emissions per capita are around 1.8 tons in France, compared to an EU average of 1.6 and similar to several neighboring countries like Germany and Belgium but above the Netherlands and Italy (1.5) (Figure 2). France's emissions per capita have declined from 2.24 in 2002, at an annual rate of around one percent.

Differences across countries can be analyzed by disaggregating road transportation emissions into vehicle ownership, distanced travelled, and emissions-intensity (Figure 2). In France, each heavy goods vehicle travels far more than that in neighboring countries (with Germany being the most similar) at around 70 percent above the EU average, while vehicle kilometers travelled (VKT) per passenger vehicle is similar to comparator countries and the EU average.⁴ Passenger and light vehicle ownership is among the highest in Europe and above all comparators except for Italy. The emissions-intensities of passenger and light vehicles are much better than the EU average and most peers.

Electric vehicles, inclusive of plug-in hybrids (PHEVs), are progressively making up a larger share of new vehicle sales, including for heavy goods transport (Figure 2). 25 percent of new passenger car sales were EVs in 2023, up from 11 percent in 2020 (IEA 2024), and in line with the EU average. Due to the long lifespan of vehicles, EV's still are a small share of total passenger vehicles (i.e., the vehicle stock) at 4.1 percent in 2023. The share of new heavy goods vehicle registration that are electric is among the highest in the world at 6.2 percent in 2023 (IEA 2024) but still well below that of passenger vehicles, reflecting the relatively large price

⁴ The higher distance per vehicle could reflect the relatively low population density/large area of France. Overall, France relies less on roads for heavy goods transportation at 21 percent than does Germany (55 percent) and Belgium (47 percent) but more than Italy (18 percent), Spain (17 percent), Denmark (15 percent) and the Netherlands (15 percent) (<u>Eurostat</u>). gap between zero emissions and fossil fuel powered heavy goods.⁵ Public charging stations have rapidly expanded since 2020.

Overall, passenger vehicles tend to have better fuel economy in France than in peer countries and the EU average (Figure 2). This can be mostly attributed to relatively high fuel economies for ICEVs in France, rather than higher EV sales shares (Figure 2)—ICCT 2021 highlights that French consumers purchase lighter (and more fuel efficient) ICEVs and more gasoline powered vehicles, which has a 15 percent lower carbon content than diesel. Light commercial vehicles (around 150 g per km on average) also have better fuel economy in France than other European countries, as do most French automobile producers compared to those of non-French companies (ICCT 2021).



⁵ The larger price gap for heavy goods vehicles is due to the need for bigger batteries, which weigh more (reducing the weight that trucks can carry, called the payload penalty) and are the most expensive component of electric vehicles. Heavy goods electric vehicle production also lags in reaching economies of scale and requires a well-coordinated public charging infrastructure along long-distance routes. These higher costs are not yet offset by the relatively high share of total ownership costs related to fuel where EVs have an advantage due to lower costs per kilometer.

The French government has committed to reducing road transportation sector emissions to 81 Mt by 2030, amounting to a 40 percent reduction below a scenario with current policies (SGPE 2023). The majority of emissions reductions are expected to come from passenger transport, primarily through electrification and less emissions intensive ICEVs and shifting passenger transport to rail, bus, and cycling. Light and heavy goods are projected to make up the remainder of abatement through less emissions-intensive ICEVs, sobriety, and modal shifts to rail and river transport, while the contribution of zero-emissions vehicle penetration is more modest (SGPE 2023).⁶ In addition to sector wide mitigation targets, France also targets an EV share of passenger vehicle sales of 66 percent and 15 percent of the stock by 2030, as well as 51 and 50 percent of new sales for light and heavy-duty commercial vehicles.

Key Considerations Related to Road Transportation Policies

Before describing and evaluating the existing policy package and reforms options, it is important to clarify the potential objectives of road transportation policies across fiscal, efficiency, environmental, and distributional dimensions.

On fiscal, the government currently raises substantial revenue from existing transportation policies, but revenue is projected to decline and spending on subsidies to slightly increase. Maintaining current levels of revenue requires increasing taxes on electricity for EV charging and vehicle purchases (to reflect the relatively high capital-intensity of EVs) and/or imposing charges per distance driven—if introduced in isolation, such an adjustment would have an adverse environmental impact by disincentivizing EV purchases. Subsidies for EV purchases and charging stations have a negative impact on the fiscal balance and projected to increase unless phased out.⁷ Policy reforms that promote decarbonization without introducing new charges on vehicle purchases and driving will reduce revenue due to erosion of existing tax bases, while price-based policies, such as the ETS with auctioned allowances, carbon and fuel taxes, and distance-based charges, are revenue raising. A key benefit of revenue-raising decarbonization policies is that at least a portion of the revenue can be used to support vulnerable households and firms, which can ease political constraints.

Economic efficiency, environmental costs, and fiscal impacts are closely related. The objective of road transportation policies may be to reduce transportation externalities (i.e., environmental costs) by changing consumer and firm decisions around the fuel economy of vehicles (extensive margin) and driving amounts (intensive margin). However, by definition, policy-induced changes in behavior generate economic costs so a practical policy priority may be to achieve the intended change in behavior (e.g., environmental benefits) at a minimal economic cost—this is generally achieved by a broad-based pricing policy, such as economy-wide carbon pricing, since it provides the same incentive for all households and firms to reduce environmental damages, leading to the lowest cost abatement opportunities being exploited.⁸ An alternative (and somewhat conflicting) objective may be to raise revenue from road fuel taxes—revenue generation is maximized when households and firms do not adjust driving and vehicle purchase decisions in response to the tax, which also results in little economic costs due to the lack of changing behavior.

⁶ For specific numbers, 28 Mt of emissions reduction is projected from passenger vehicles vs. 17 Mt from light and heavy goods. For passenger vehicles, EVs and more fuel efficient ICEVs contribute 14 Mt, modal shifts 5 Mt, carpooling 3 Mt, biofuels 3 Mt, and teleworking/sobriety 3 Mt. For light and heavy goods, improvements in emissions-intensity and zero-emissions vehicles contribute 11 Mt, sobriety 7 Mt, modal shifts 4 Mt, load/logistics optimization 3 Mt, and biofuels 3 Mt.

⁷ To maintain a consistent abatement cost over time and calibrate subsidies to the size of positive spillovers, subsidies should decline as the technology matures and the emissions-intensity of vehicles decline.

⁸ The government can also play a role in supplying public goods that provide alternatives to harmful activities, such as public transportation, and reduce the cost of abatement.

Regardless of whether the policy objective is to raise revenue or reduce environmental damages, a welfare maximizing policy (i.e., a first-best policy) is to adequately price environmental costs. This is achieved with a policy that equalizes social and private prices using charges equal to the marginal cost of the externality, which maximizes welfare since externalities are only generated if the benefit to the household or firm exceeds the marginal societal cost. The relevant first-based policies for each key driving and pollution-related externality are: (i) for climate change damages, a carbon price equal to the carbon price implicit in France's mitigation target,⁹ (ii) for domestic health costs of local pollution, a tax per ton of local pollutant emitted with the tax level varying based on exposure of vulnerable populations (e.g., the elderly) to local pollutant emissions, (iii) for congestion, a charge set at the marginal cost of congestion in real-time, (iv) for road accidents, insurance premiums that varies according to distance driven and the risk of the driver, which may emerge through private markets or with government incentives, and (v) for road damage, a per kilometer charge based on axle weight for heavy goods vehicles. GPS and technology improvements related to tolling allow for these measures to be practically implemented with the exception of local pollutant and (potentially) driver risk charges/premiumsthese could be priced through annual vehicle registration fees that vary based on pollution characteristics of the vehicle and distance driven or, more bluntly, higher fuel excises. Various ways to approximately achieve firstbest outcomes are evaluated in this paper.

Distributional impacts are not comprehensively quantified in the analysis but discussed where relevant. Given that households vary in the share of consumption allocated to road transportation and their abatement costs (e.g., switching from a ICEV to an EV may be costlier for a family that requires a van), road transportation policies will have differential impacts across the income distribution. The same is true for firms, which differ in terms of the share of costs from road transportation, ability to undertake modal shifts, etc.

Road Transportation Sector Policies

There are a suite of existing and planned EU and domestic policies that impact transportation emissions. The policies can generally be categorized as market-based measures that impose a charge on emissions; market-based measures that do *not* charge emissions; subsidies; and regulations. The rest of this section summarizes the economics of each policy type, describes France's relevant policies, and quantifies the impact of France's existing policies.

Market-Based Policies that Charge for Emissions

Market-based policies that charge for remaining emissions provide environmental, fiscal, and economic advantages, but are more politically difficult in the near-term. Such policies include fuel taxes and carbon pricing and follow the "polluters pay" principle since those who emit are required to pay. These policies minimize economic costs to achieve a given emissions reduction since they incentivize the full range of behavioral responses to cut emissions (e.g., reductions in driving levels and switching to less emissions-intensive vehicles and transportation methods) and improve the allocation of resources across the economy (to the extent that taxes are at or below marginal external costs) since they force households and firms to consider the cost of harmful pollution when making consumption and investment decisions. The resulting higher energy costs can lead to social resistance, highlighting the importance of using revenues to compensate vulnerable households and firms, increase spending on public goods, and/or reduce taxes on productive activities like

⁹ Alternatively, the social cost of carbon or the carbon price implicit in achieving global mitigation targets could be used. The resulting carbon price may vary considerably across options. For example, recent studies on the social cost of carbon find it to be around USD 200 per ton (US EPA 2023a, RFF 2023), while the additional carbon price needed to achieve 2C has been estimated to be between USD 50 and 100 per ton (Stern and Stiglitz 2017, Black et al 2023c).

work and investment. In the long-run, analysis shows that policies that charge for emissions are necessary to achieve net zero emissions while preserving fiscal space for key government services, such as health and education, which is also politically difficult (IMF 2023).

France's domestic road fuel taxes and the forthcoming EU ETS II fall into this policy category (Table 1). Road fuel taxes include excises on diesel and petrol, which is made up of separate carbon and non-carbon components but also includes a partial rebate for heavy goods vehicles, and the value-added tax of 20 percent—road fuel excises in France are above EU averages (Figure 3). France's electricity excise is about one-third that of petrol and diesel on an energy equivalent basis but still two- and four-times EU averages for households and firms, respectively (Figure 3: Road fuel and electricity taxes across EU countries in 2023). A second EU ETS will be introduced in 2027 or 2028 and apply to emissions in the transportation sector, in addition to buildings and industrial emissions not covered in the original ETS.¹⁰ It is unlikely that the EU ETS II will impact road transportation fuel prices this decade since the ETS price is capped at €45 per tonne until 2030 and France could either remove its domestic carbon price when the EU ETS II is introduced or keep the domestic tax and receive an exemption. The distance-based toll on heavy goods vehicles, which is paid directly to the road concessionaire, provides decarbonization incentivizes since it is higher for more polluting vehicles and reduces distance driven, helping to correct for driving related externalities, such as road damage, congestion, and accidents. The revised Eurovignette system requires differentiated heavy goods tolls based on CO2 and local air pollutant emissions and potentially other factors, such as congestion, but France has stated that it will not introduce such differentiated tolling before 2031 due to contractual obligations under its current road concessions (T&E 2024).



Market-Based Policies that do not Charge on Emissions

Market-based policies that do not charge remaining emissions are less effective but can provide strong decarbonization incentives and improve politically acceptability. Such policies include feebates and tradable fuel economy standards. These policies incentivize reductions in emissions-intensity of an activity but without significantly impacting its quantity (e.g., switching to more fuel-efficient vehicles but maintaining the same level

¹⁰ The EU has also been discussing a revision of the Energy Tax Directive (ETD) (EC 2023). France's excises, even when excluding the carbon price component, are well above these levels so they are unlikely to be impacted by any change in the ETD. of driving) and, thus, do not exploit the significant portion of abatement opportunities that come from reducing driving levels; they do not increase household and firm costs except through the higher cost of purchasing more fuel-efficient capital, which is a relatively small portion of decarbonization costs at low levels of abatement, making these policies more politically acceptable; but they do not raise revenue and will indirectly result in lost revenue to the extent that they erode the fuel tax base. They also will exacerbate driving related externalities as people drive more as the marginal cost of driving falls with improved fuel economy.

France's malus system and the EU's passenger fuel economy standard fall into this policy category (Table 1). The malus écologique, which applies to newly registered passenger cars that are purchased by individuals, imposes a one-time sliding scale levies on vehicles with emissions above 118 grams of CO₂ per kilometer, and the weight penalty charges ICEVs (but not plug-in or battery EVs) on each kg above 1,600 (Figure 4).¹¹ A relatively small number of vehicles are covered by the malus regimes (estimated to be 10 percent for the weight malus and a similarly low amount for the CO₂ malus prior to recent changes to the pivot point) since thresholds are set above that of the average vehicle purchase (SGPE 2023) and the quickly escalating tax schedules are effective in shifting purchases to non-taxed vehicles. Company cars are subject to an annual tax based on the CO2 emissions-intensity and Euro grade of the vehicle, with both only applying to ICEVs. Heavy goods vehicles pay an annual tax according to weight and number of axles, but without an environmental component. The EU's separate fuel economy standards for passenger, light commercial, and heavy goods vehicles require vehicle manufacturers to meet increasingly stringent targets, which are aligned with Fit for 55 objectives—these standards allow for pooling across manufacturers, which improves the flexibility and cost-effectiveness of the system. France does not have a "malus" system for heavy goods vehicles.



¹¹ The pivot point for the malus ecologique was 123 grams of CO2 per kilometer in 2023. In 2024, the weight threshold declined from 1,800 to 1,600 kg and the fees are €10 per kg above 1,600 for vehicles between 1,600 and 1,799 kg and progressively increasing as the car weight crosses specific weight thresholds.

Subsidies and Other Policies

Subsidies are generally more politically acceptable and can support equity objectives but with fiscal and economic downsides. These policies include direct cash grants, reduced VAT, and concessionary lending for decarbonization-related activities, such as research and development and EV purchases. Since subsidies tend to target only one behavioral response (e.g., the purchase of an EV), they are less efficient in reducing emissions. However, they may address market failures, such as learning by doing, network effects, and financial frictions for low-income households, and can promote equity when they are well-targeted.¹² Subsidies are fiscally costly, with costs increasing in tandem with environmental effectiveness, and result in either higher taxes or reduced government spending over the long-term unless they cost-effectively raise productivity.

France has a suite of subsidies for low emissions vehicles (Table 1). The most prominent is the bonus écologique, which provides a subsidy for the purchase of passenger zero-emissions vehicles of up to €7,000 with the amount varying based on the buyer's income level, the vehicle's purchase price, and other characteristics. Heavy goods vehicles can receive a scrappage bonus of up to €50,000. Regional governments also provide grants of up to €6,000 and €13,000 for the purchase of zero-emission passenger and heavy goods vehicles. There is also a means-tested leasing program that provides concessionary EV leasing rates (€100-150 per month). As of 2024, all EV subsidies are conditional on the emissions-intensity of production, which excludes about 35 percent of EVs sold in the French market in 2023.¹³ France also provides grants for the purchase of residential EV charging stations and public charging points, including at condominiums and employers. Green industrial investment is subsidized through a green investment tax credit of 20 to 45 percent.

There are several other policies that support road transportation decarbonization in France. These include low emissions zones in over ten French cities (which prohibits or restricts vehicles with high local air pollutant emissions), public investment in the rail system and cycling infrastructure, increased biofuel blending requirements, and electricity sector planning to support grid resilience and suitability for increased electricity demand.

Market-Based Policies that Charge for Remaining Emissions			
Policy	Details		
Excise tax on fuels (EC	€0.59 and €0.68 per liter specific tax for diesel and unleaded petrol; of which €0.12 and		
2024a)	0.10 per liter of diesel and petrol, respectively, comes from the carbon price of €44.6 per		
	ton of CO₂; a rebate of around €0.15 per liter for diesel used for heavy goods transport		
EU ETS II (EC 2023)	Capped at €45 per ton (in real 2020 prices) until the end of 2029 (30h) and allowances will		
	linearly decline at 5 percent per year from 2024 emission levels		
Value-Added Tax (EC	20 percent applied to diesel and unleaded petrol, and all vehicle purchases		
2024a)			
Distance charge (GoF	€0.13 per km levied through by road concession operators, with rates varying by axle rate		
2014 <u>)</u>	and pollution		
Market-Based Policies that do not Charge for Remaining Emissions			
Policy	Details		
Malus écologique (GoF	One-time levy on newly registered passenger vehicles; levies increase with emissions-		
2024a)	intensity above 118 grams of CO ₂ per kilometer		

Table 1. Decarbonization Policies	Applied to Road	Transportation	Activities in France
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¹² On equity, the ultimate incidence of the subsidy depends on how it is financed.

¹³ The subsidy could be made more efficient by applying a continuous adjustment to the subsidy level based on the emissionsintensity of vehicle and battery production, rather than a binary eligibility threshold,

Weight penalty (GoF	One-time levy on newly registered passenger vehicles; levy increases with weight above
2024a)	1,600 kilograms; EVs are exempt
Annual CO ₂ tax (GoF	Annual tax on company cars; tax increases with emissions-intensity but does not consider
2024b)	distance driven
Annual atmospheric	Annual tax on company cars; tax increases with worsening Euro-grade but does not
pollutant tax (GoF 2024b)	consider distance driven
Passenger and light	The following targets apply to new vehicles: 95 g per km for passenger and 147 for vans in
vehicle emissions	the period 2020-2024, 93.6 for passenger and 153.9 for vans in 2025-2029, 49.5 for
standards (EC 2024b)	passenger and 90.6 for vans in 2030-2034, and all zero-emission after 2034
Heavy goods emissions	45 percent reduction in emissions per km for new vehicles by 2030 relative to 2019-2020
standard (EC 2024c)	levels, 65 percent for 2035, and 90 percent for 2040
Subsidies and Other Polic	ies
Policy	Details
Bonus écologique (GoF	A means-tested subsidy for zero-emissions passenger vehicle purchases of up to €7,000
2024c)	for EVs with costs below €47,000 (€4,000 for those above an income threshold);
	conversion premium for scrapping a highly polluting vehicle of up to €6,000; additional
	€1,000 if living or working in a low emissions zone; regional governments can provide
	additional grants
Retrofit bonus (GoF 2024d	A subsidy of up to €50,000 for replacing an ICEVs heavy goods vehicle with a zero-
and GoF 2024e)	emissions vehicle, along with accelerated depreciation
Social leasing program	Subsidized leasing EV rates of €100-150 per month for low-income households that drive
	more than 15 kilometers to work
Charging subsidies	A tax credit of €330 per individual charger; up to 50 percent subsidy for shared chargers at
	condominiums and 40 percent at employers; reduced VAT of 5.5 percent for installation;
	regional governments can provide additional grants
Green investment tax	A 20-45 percent tax credit for investment in manufacturing batteries and other low carbon
credit and grants	technologies, as well as direct state aid through grants
Biofuel blending mandate	14% biofuel blending, with at least 3.5% being advanced biofuels
Low emissions zones	11 cities currently have zones where the use of highly polluting vehicles is restricted; it is
	expected that 32 areas will have such zones in place by 2025

Evaluation of Existing Policies

A technoeconomic model is used to forecast road transportation emissions and revenue from fiscal mitigation instruments, and assess impacts of policy reforms in France. The model performs separate calculations for light-duty vehicles (cars and light commercial vehicles) and heavy-duty vehicles, with further disaggregation between used and new vehicles and ICEVs and EVs, given the variation in policies and economics across vehicle types. The analysis captures interactions across policies, which is important given the web of EU and domestic road transport policies. As with any model, there are several simplifying assumptions—for example, modal shifts are not explicitly modelled, vehicle ownership levels are exogenous, and general equilibrium impacts like changes in employment and trade are not captured—but these simplifications are not expected to significantly alter results. See Annex I for more details on the model.

All major policies are explicitly modelled, and additional emissions reductions are assumed to come from nonmodelled policies. Specifically, modelled policies cover (i) the malus and weight penalty (assumed to be a shadow carbon price of €150 per ton for ICE purchases with the pivot point declining by four percent per year);¹⁴ (ii) EV subsidies (assumed to be $\notin 2,500$ per vehicle for passenger and light vehicles and $\notin 50,000$ for heavy goods and reducing annually to be fully phased out by 2035);¹⁵ (iii) charging station subsidies (assumed to cover 50 percent of charging costs and be phased out by 2030);¹⁶ (iv) EU ETS II (assumed to remain at $\notin 45$ per ton from 2027-29 and then increase by $\notin 10$ per ton starting in 2030 but with France's fuel tax reduced by $\notin 45$ when the ETS is introduced); (v) EU fuel economy standards for new passenger and heavy goods vehicles (modelled as the shadow carbon price needed to achieve the standard); (vi) heavy goods tolls ($\notin 0.13$ per km but does not vary by CO2 intensity given France's announcement to not introduce differentiated tolls prior to 2031), and (vii) energy taxes are held at 2023 levels and indexed to inflation.¹⁷ To account for decarbonization levers that are listed in SGPE 2023 but potentially not induced by the explicitly modelled policies (e.g., increased biofuel use), an additional six and three Mt reduction in passenger/light commercial and heavy goods, respectively, are assumed to occur exogenously.¹⁸

Road transportation emissions are projected to fall to 94 Mt by 2030 under current policies but still exceed the carbon budget (Figure 5). Emissions from passenger and light vehicles decline from 88 Mt in 2023 to 66 Mt by 2030 due to improving fuel economy of ICEVs (mostly caused by the malus regime and EU ETS II) and growing EV uptake. Over half of new car sales are EVs by 2030 and 100 percent by 2035, as EV prices fall from technological improvements, mainly in the cost of batteries, and the EU fuel economy standard tightens, while around 40 percent of used cars are EVs in 2030 (with the difference between and new and used EV sales more due to a limited used vehicle supply rather than economics). Emissions for heavy goods vehicles fall slightly slower (17 percent reduction relative to 22 percent for passenger vehicles by 2030) but still decline significantly as EV uptake grows with falling EV costs, strengthening of fuel economy standards, and the introduction of the EU ETS II is introduced. Emissions exceed the carbon budget starting in 2024 and the SGPE road transportation target of 81 Mt in 2030.

Emissions projections follow similar trends to that of other models, providing a robustness check. The SGPE 2023 transportation report finds that 2030 road transportation emissions would be 114 Mt under existing policies and that 35 and 52 percent of the emissions reduction needed to reach 2030 targets for commercial and passenger vehicles, respectively, are achieved under existing policies (SGPE 2023). The European Environmental Agency (EEA) estimates that existing policies result in 2030 emissions of 95 Mt and 82 Mt by 2035 (EEA 2023). Estimates from the model used in this paper are broadly in line but slightly lower than that of the EEA over the medium-term and lower than those from SGPE 2023. Since key policies are explicitly modelled and exogenous reductions from other decarbonization levers are assumed, one can be reasonably comfortable in results presented in this paper. However, it is difficult to assess the reasons for different results across models due to a lack of documentation.

¹⁴ A shadow carbon price of €150 per ton provides similar decarbonization incentives to the existing malus. The pivot point declines annually to reflects the recent policy trend—it was 133 g per km in 2021, 128 in 2022, 123 in 2023, and 118 in 2024.

¹⁵ In 2023, spending on EV subsidy was €1.147 billion (GoF 2023c) and EV sales were 461,430, amounting to an average EV subsidy of around €2,500 per vehicle.

¹⁶ The phasing out of EV purchase subsidies does not reflect France's stated policy intention but is more so the experience in other countries with growing EV uptake, such as China, Germany, and Norway.

¹⁷ The fuel standards are assumed to apply to France in isolation (i.e., without considering the rest of the EU) and modelling does not capture the impact of "supercredits" for zero-emissions vehicle sales.

¹⁸ Additional emissions reductions outside of the explicitly modelled policies are assumed to come from increased biofuel use, carpooling, modal shifts, teleworking, river and road freight, and e-fuels and result in reductions of 8 and 4 Mt for passenger/light commercial and heavy goods, respectively (SGPE 2023). It is not clear whether modelled policies drive decarbonization through these levers (e.g., the EU ETS II promotes biofuel use, increased occupancy rates, and modal switches) so only three quarters are assumed to come from non-modelled policies while the other quarter is assumed to come from modelled policies.



Revenue from taxes on fuel, driving, and vehicle purchases taxes is projected to fall steadily as vehicles shift to relatively lightly taxed EVs (Figure 6). Currently, revenue generated from road transportation is estimated to be around 1.4 percent of GDP, largely due to excises on diesel and petrol for road transportation (~1 percent of GDP) and VAT on fuel and vehicle purchases (~0.4 percent of GDP) while the malus and driving tolls raise relatively little revenue and the EV and charging subsidy costs around 0.1 percent of GDP.¹⁹ As the share of EVs increases and gasoline and diesel fuel use decline, revenue steadily falls by about 0.07 percentage points per year, reaching one percent of GDP by 2029. The decline in revenue from 2019 to 2023 is largely attributed to a lack of indexing excises to inflation, improved vehicle fuel-intensity, and less driving relative to income. Total revenue from vehicle acquisition, fuel, and other taxes exceeded that of Norway and Sweden in 2021.

The existing policy package makes the average household better off compared to a policy with only VAT (Figure 6). The economic efficiency costs from households and firms buying more expensive but cleaner vehicles and driving less (in response to taxes, subsidies, and fuel economy standards) are around 0.1 to 0.5 percent of GDP out to 2030 but increase afterwards as the EU's fuel economy standards become more stringent.²⁰ However, the benefits from reduced driving related externalities (e.g., time saved from less congestion) and pollution (e.g., less lung and heart disease from cleaner skies due to lower diesel consumption) more than offset the economic costs. Most environmental benefits derive from reduced driving-related externalities in the short-term but, as the fleet shifts to EVs, these benefits decline due to low taxes per kilometer driven for EVs as compared to an ICEVs (Figure 9). Pollution benefits from reduced fossil fuel use increase over time as the social cost of carbon increases (up from €54 in 2020 to €500 in 2040, French

¹⁹ Given that revenue outturns are not available at the individual tax and energy product level, these are estimated as the statutory tax rate multiplied by fuel consumption.

²⁰ The economic efficiency costs of the EU fuel economy standards are highly sensitive to EV prices. For example, if EV prices are 25 percent cheaper than the baseline assumption by 2030 then economic efficiency costs never exceed one percent of GDP. Conversely, if EV prices are 25 percent more expensive than the baseline assumption then economic efficiency costs reach nearly two percent of GDP.

Strategie 2019). Currently, pollution from passenger ICEVs tend to be priced above efficient levels while driving related externalities for all vehicles, except for freight EVs, is undercharged and this trend worsens as the share of EV grows. See Box 1 for a description of consumer welfare calculations and a comparison of the existing policy package to efficient levels.



air pollution costs.

Additional data is needed to estimate the distributional impacts of existing policies. Middle income and rural households likely lose the largest share of purchasing power from existing transportation fuel taxes, with impacts ranging from around 3.5 percent of consumption for the average middle income, rural household to 2.5 percent for wealthier, urban households (, and somewhat similar patterns identified in Bonnet et al 2023 and Beery 2019). To the extent that EVs are disproportionately owned by wealthier households (which is implied by Vailles et al 2023 and true in some other countries),²¹ the relative low electricity tax (Figure 3: Road fuel and electricity taxes across EU countries in 2023) is regressive for the transportation sector but, overall, increasing the electricity excise would be regressive since poorer households spend a greater share of the their budgets on non-transport electricity—also, this EV ownership trend may be transitory as the used car market develops and cheaper EVs are produced. Energy taxes can turn progressive if revenues use disproportionately favors the poor and rural communities.

The distributional impact of the means-tested EV subsidies (including social leasing) and bonus/malus is not clear and depends on several factors.²² One France specific study finds that the bonus/malus

²¹ Data on EV ownership by income level in France is not readily available. However, data from Sweden and Norway show electric vehicles disproportionately owned by the wealthy especially at lower levels of uptake (Qorbani et al 2024 and Pyddoke et al 2021). Vailles et al 2023 show that cost barriers, financing constraints, and the undeveloped EV used vehicle market make EV upfront costs prohibitive for lower income households even after means-tested purchase subsidies, although the social leasing policies could improve access for poorer households.

²² Some factors include whether (i) poorer households find EVs affordable after incentives, (ii) energy efficiency (which is subsidized through the bonus/malus) is a normal good, (iii) subsidies and taxes are passed through to consumers, (iv) poorer households are disproportionately impacted by local pollution, and (v) how the net subsidy is financed.

disproportionately benefits the middle class if the net subsidy is financed through a uniform tax but is progressive when financed with a tax in proportion to income (Durrmeyer 2021). In general, the distributional impacts of feebates and fuel economy standards are understudied but a paper on the US fuel economy standards finds slight regressivity after accounting for impacts on used car market dynamics (David and Knittel 2016).



fuel is assumed.

Box 1. Estimating Welfare Impacts and Efficient Tax Levels

Welfare impacts are calculated as the reduction in environmental externalities relative to the economic efficiency costs induced by the policy.

Environmental externalities from driving focus on those expected to be largest in size—lost time from traffic

congestion; health and property damages from vehicle accidents (excluding costs that are internal to the driver); damaged roads and road maintenance; health impacts from local air pollution; and economic costs from global warming (Parry et al 2014). After establishing the monetary value of marginal environmental cost per km driven and pollutant emitted (following Black et al 2023a), the environmental benefits of a policy can be calculated as the change in km driven and pollutant emitted multiplied by the marginal environmental damage. In Figure 8, the environmental benefit of an illustrative policy is the sum of areas E, F, and G.



Economic costs are estimated using a common approach (following Harberger, 1964; see Annex I of Black et al 2023b for

more details)—this captures the cost of purchasing more expensive (and/or smaller) fuel-efficient vehicles and driving less relative to a scenario without the policy. For non-pricing policies, such as EV subsidies and fuel economy standards, a shadow price is estimated by dividing the policy amount by abated fuel use (e.g., if an EV subsidy is €5,000, discounted lifetime VKT per vehicle is 100,000 km, and the average new ICEV emits 100 grams per km, then the vehicle is expected to emit 10 tons of CO2 over its lifetime and the marginal abatement cost of the policy is €500 per ton of CO2 or €1.20 per liter of petrol). In Figure 8, the economic efficiency cost is G assuming no pre-existing policies (calculations in this paper capture the impact of pre-existing policies).

Figure 9 provides an approximation of environmental damages and fuel prices in common units, scaling both to amounts per liter or kWh based on the fuel economy of vehicles for illustrative purposes. For example, in 2030 and using 2023 constant prices, the marginal cost of congestion is estimated to be $\in 0.10$ per km (after accounting for behavioral responses), road accidents are $\in 0.015$ per km, road maintenance is $\in 0.04$ per km (only for heavy goods), global warming is $\in 242$ per ton of CO2, and local air pollution is $\in 19,000$ and 38,000 per ton of NOx and direct PM 2.5, respectively. For comparison, using the example of passenger diesel, the increase in the marginal cost per unit of fuel due to existing policies is estimated to be $\in 1.36$ per liter in 2024 (largely due to the excise and EV subsidy), $\in 1.79$ per liter in 2030 (with the increase due to the EU fuel economy standard) and increasing to $\in 5.68$ per liter in 2035 as the fuel economy standard tightens.

An efficient tax regime would price pollution related externalities equal to their costs and distance related externalities using a road user charge. In 2024, the existing system implies a price on passenger diesel pollution of ≤ 1.12 per liter through the fuel standard, bonus/malus, and fuel tax (scaled to the portion of behavioral response from improved fuel economy) compared with an external cost of ≤ 0.85 per liter (climate and local air pollution) and a price on driving of ≤ 0.25 per liter (fuel tax scaled to behavioral response from reduced driving) and external cost of ≤ 1.76 per liter (congestion and accidents). This pattern of overcharging for pollution and undercharging for driving is consistent across fuels for passenger vehicles and projected to grow as pollution related disincentives increase (with the fuel economy standard), driving related charges remain stable, and the value of time, mortality, and pollution costs grow. Both pollution and driving related externalities from diesel freight vehicles are underpriced as is driving related externalities from freight EVs. Driving related costs from passenger EVs are significantly underpriced.



The Impact of Potential Reform Measures

Transitioning to road user and congestion charges, applied at economically efficient levels, would allow France to achieve road transportation mitigation targets, providing a resilient source of fiscal revenue and significantly reducing transportation externalities, such as congestion. Building the administrative capacity to implement these charges, while considering proxy distance charges and higher energy taxes in the interim, could ease the transition to distance charges and provide near-term fiscal and externality benefits. Smaller adjustments to the existing fiscal system, like converting the bonus/malus to a revenue-neutral feebate, provide valuable but marginal fiscal and environmental benefits and are unlikely to close the gap to emissions targets. Detailed analysis of distributional impacts and Complementary policies, such as income-based support, reduced public transit fees, and improving accessibility of public transportation, are needed to understand and address impacts and build public support.

Quantitative Assessment of Policy Reform Options

Description of Evaluated Reform Options

Seven road transportation policies options are analyzed, using the existing policy package as a baseline (Table 2). The analyzed policies range from overhauling the existing policy package using first (or second) best distance-based, congestion, and/or pollution charges (policies 4-7 listed in Table 2) to options that improve decarbonization incentives for heavy goods transport (2) to adjustments of the existing fuel tax, subsidy, and malus regime (1, 2, 3). In all cases, EU level policies are maintained, which has important implications for the design of domestic policies (e.g., the level of efficient fuel taxes). Also, unless noted in the descriptions below, existing policies (e.g., EV subsidies) are also maintained.

Policy	Description	Objective	
Folicy		Objective	
1. Retain domestic	The EU ETS II is applied on top of the existing domestic carbon price of	Fiscal revenue, emissions	
carbon price	€44.6 per ton	reductions	
2. Introduce a linear	Convert the malus/bonus regime to a linear, revenue-neutral, €250 per ton of	Fiscal revenue, emissions	
feebate	CO₂ feebate with a separate schedule by vehicle category; increases by €10	reductions for heavy	
	per ton annually after 2030	goods	
3. Increased EV	Increase average subsidies to €5,000 per passenger and €130,000 per	Ease political constraints,	
subsidies	heavy goods vehicle in 2025 and phased out through 2040	equity	
4. Efficient road user	Introduce a distance-based charge equal to the marginal external cost of		
and congestion	non-congestion externalities and a congestion charge limited to driving	Address system slitics	
charge (RUC)	during peak hours (12% of total driving); remove the existing bonus/malus	Address externalities	
5. Efficient energy	Adjust taxes on electricity and fossil fuels to capture the full marginal external		
taxes	cost of driving but scaled down for fuel economy improvements and fuel	levenue	
	standards; remove the existing bonus/malus		
6. Efficient RUC and	Combine the above two reforms but scale down fuel taxes relative to policy 5		
fuel taxes			
7. Partial efficient	Policy 6 but at half of the efficient level for political acceptability purposes		
RUC and fuel taxes			
Source: Author. Note: When determining the efficient fuel tax level, the marginal external cost per liter or kWh of fuel is scaled			
downward to account for the driving portion of the fuel price elasticity (i.e., excluding the portion of the behavioral response that			
results in more fuel-efficient vehicles) and further downward adjustments given the incentivize to improve emissions-intensity from			
the EU fuel economy standard and reduce driving through road user charges on heavy goods and, potentially, passengers.			

Table 2. Analyzed Reform Options

Impact on Total Cost of Ownership

Feebates and subsidies directly impact the purchase price of vehicles and slightly lower the cost of driving as vehicles become more energy efficient (Figure 10). The feebate adjusts the relative price of low vs. high emissions vehicles but without changing the price of the average vehicle (based on their emissions-intensity, PHEVs would be lightly subsidized under a revenue-neutral feebate), while the EV subsidy only reduces the price of zero-emissions vehicles and leaves the price of ICEVs unchanged.²³ The purchase price of vehicles is also impacted by the EU fuel economy standard, which increases prices for ICEVs that have emissions-intensities above the standard and decreases prices for vehicles below the standard with this impact growing over time as the fuel standard becomes more stringent. There are second-order impacts on total fuel costs from improved fuel economy and greater EV uptake, with the latter reducing the per-unit overhead costs for charging infrastructure (e.g., see Basma et al 2021).

Efficient energy and distance taxes and retaining the domestic carbon price directly result in increased driving costs, with a few exceptions on uncongested roads (Figure 10). The domestic carbon price only increases driving costs for ICEVs and does so by around 4 percent after accounting for behavioral responses, respectively, while efficient taxes increase costs for all vehicles since they imply a higher charge for distance driven regardless of vehicle type.²⁴ Since distance and energy taxes equalize treatment of driving related externalities (other than pollution externalities, which are higher for fossil fuels), they, raise fuel costs for passenger EVs more than for ICEVs given the relatively light existing taxation of electricity.²⁵ For example, under the efficient fuel tax, gasoline prices are estimated to remain relatively stable (since existing taxes are near efficient levels) but passenger and freight diesel prices increase by 60 and 5 percent, respectively, and passenger electricity prices increase by over 100 percent (**Figure 9**). For road user and congestion charges, the change in driving cost depends on whether the driver is on a congested road and, in some cases, driving costs decline on uncongested roads since existing charges are estimated to be above efficient levels (e.g., for gasoline passenger vehicles). All efficient taxes grow with living standards (i.e., value of time and life).

The impacts on total cost of ownership (TCO) changes are much smaller than the changes in fuel costs, especially for passenger vehicles. Fuel costs are estimated 10 to 20 percent of the TCO for the average passenger EVs and ICEVs, respectively, but approach 50 percent for freight ICEVs and 30 percent for freight EVs since freight vehicles are driven more.

²³ Under the feebate, the bonus/malus schedule is equal to the feebate price * (emissions-intensity of purchased vehicle – previous year's average emission-intensity), where the feebate price could be converted into a shadow carbon price by dividing by the expected lifetime emissions for the average vehicle. The pivot-point could also be shifted downward (e.g., 20 g per km below the previous year's average) to maintain the malus' existing revenue.

²⁴ To avoid the tax adjusting annually to account for sharing in the EU fuel economy standard, which seems impractical, the price signal from the fuel economy standard in 2030 is used (around €0.57 per liter of passenger gasoline, €0.64 per liter of passenger diesel, and €0.19 per liter of heavy goods diesel). A more flexible efficient fuel tax would require annual adjustments to account for the changing marginal abatement cost stemming from the EU fuel economy standard, implying a declining tax as fuel standard gradually tightens.

²⁵ In 2025 and when introduced in isolation, the efficient road user charge results is €0.14 and 0.18 per vehicle-km for passenger and heavy goods vehicles on congested roads and €0.015 and €0.05 on uncongested roads, respectively; and the efficient energy tax is €0.72, 1.10, and 0.85 per liter of petrol, diesel for passenger vehicles, and diesel for heavy goods and €0.28 and 0.01 per kWh for passenger and heavy goods EVs.



Emissions Reductions

All policies except those with the efficient road user charge lead to emissions exceeding the medium-term carbon budget. The evaluated policies result in varying reductions of emissions over the next five years but emissions levels somewhat converge by 2035 due to the EU's fuel economy standards. Still, near-term impacts are important for achieving carbon budgets and other climate targets. The policies with efficient RUC lead to the largest near-term decline in emissions due to large reductions in driving, respectively. Emissions under the linear feebate and carbon price generally follow that of the existing policies but with a reduction of one to three percent. The increased EV subsidy, efficient energy tax, and partial road user charges cause emissions reductions of 5-6 percent. Policies that only impact new vehicle purchases, such as the EV subsidy and feebate has slower moving impacts given the slow turnover of the vehicle fleet.

Under most policies, emissions reductions are predominantly driven by purchases of less emissions-intensive vehicles, rather than reduced driving. Existing policies lead to a 25 and 32 percent improvement in the fuel economy of heavy goods and passenger vehicles, respectively, in 2030 relative to 2023 levels but driving distances increase.²⁶ The feebate, efficient energy taxes, and EV subsidies cause larger fuel economy improvements for heavy goods vehicles (up to 34 percent in the case of larger subsidies) since they provide an increased incentive to shift to cleaner ICEVs and/or EVs. Distance driven per passenger vehicle increases slightly more for policies that promote increases in fuel economy but do not charge for remaining emissions since improved fuel economy standard and bonus/malus), feebate, and EV subsidies (due to EV's having a lower marginal cost per kilometer driven from their around 300 percent better energy efficiency for passenger vehicles).²⁷ Efficient road user charges reduce driving by 19 percent for passenger vehicles but do not encourage switching from ICEVs to EVs nor reductions in the emissions-intensity of ICEVs since the charge does not vary according to carbon content, while energy taxes, including carbon prices, encourage both reductions in emissions-intensity and driving distances.²⁸

The share of EVs in vehicle sales and the vehicle stock shows slightly more variation across policies. EV sales reach 60 and 49 percent of new passenger and heavy goods vehicle sales by 2030 with the increased EV subsidies, compared to 54 and 37 percent under existing policies and targets of 66 and 50 percent, respectively. The linear feebate also leads to a significant growth in heavy goods EVs sales, while maintaining the domestic carbon price causes small increases in EV uptake. Passenger vehicle EV sales are lower under the efficient RUC and energy tax regimes given that they increase taxes on EVs and the EV subsidy is assumed to be removed—maintaining the EV subsidy would result in five percent higher passenger EV sales. The stock of passenger and heavy goods EVs lag sales by about 20 and 10 percent on average, respectively, given the slow turnover of the vehicle stock, although heavy goods vehicles turnover about twice as quickly.

²⁶ Changes in driving distances is due to increasing population growth (two percent in 2030 relative to 2023), vehicle ownership per capita (eight and nine percent for passenger and nine heavy goods, respectively), and distance driven per vehicle (eight and four percent, respectively). Distance driven per vehicle increases with income and switching to EVs, which have lower marginal costs per km. Ownership per capita increases with income.

²⁷ The evidence on whether EV are driven more than ICEVs is largely mixed for studies focusing on the US (e.g., Zhao et al. 2023, Burlig et al. 2021, Metcalf and Doshi 2023). A Norwegian study finds EVs are driven more then ICEVs (Rystad Energy 2023). It is assumed that EVs are driven slightly more than ICEVs, weighting the results from the Norwegian study more since public charging infrastructure, which could be a barrier to VKT in EVs, is more advanced and thus has more external validity for countries with high EV update.

²⁸ The reduction in driving under the efficient distance charge is negligible for heavy goods since the efficient charge is similar to the existing per kilometer charge on heavy goods vehicles.



Fiscal Impact

Efficient taxation generates additional revenue of 0.8 to 1.7 percent of GDP, depending on the design. Road user charges and energy taxes provide a resilient revenue stream since the charges apply to all driving rather than only fossil fuel use and tax rates increase with the value of time and statistical life. The road user charge generates relatively more revenue, and only slowly declines over time as the increase in driving levels does not fully keep up with higher GDP due to an income elasticity of driving below one. The combination of efficient road user charges and energy taxes primarily generates revenue from the distance portion of the tax rather than pollution since driving related externalities are larger and less responsive to taxation, resulting in less tax base erosion.

Revenue slowly declines for the carbon price and feebate policies but at a slightly slower rate than under existing policies. The carbon price simply generates greater revenue through levying a higher charge on carbon emissions, raising around 0.1 percent of GDP more than existing policies in 2030, but the tax base is eroded over time as the vehicle fleet transitions to EVs. The revenue-neutral feebate replacing the existing bonus/malus regime results in higher revenue since the bonus/malus is projected to cost around 0.1 percent of GDP in 2030.

The increased EV subsidy leads to a fiscal cost of around 0.3 percent of GDP in 2030, relative to existing policies. The cost of the EV subsidy grows with higher EV purchases more than offsetting the declining subsidy level, which is increased to €5,000 per passenger and €130,000 per heavy goods vehicle in 2025 and phased out through 2040. One advantage of a feebate as compared to a subsidy regime is that the EV subsidy amount under the feebate automatically adjusts to account for growing EV purchases to be approximately revenue neutral.



Given the size of the driving cost increase and uncertainty over political acceptability of distance and congestion charges, it is useful to understand how impacts vary across a range of policy stringencies (**Figure 18** in Annex II). A road user charge of one cent per kilometer raises revenue of about 0.15 percent of GDP, and the congestion charge raises revenue by an additional 0.2 percent of GDP. Emissions targets are met once the road user charge reaches 5 and 7 cents per kilometer with and without the congestion charge, respectively.

Welfare Impact

Economy-wide, annual welfare impacts are evaluated relative to the existing policy scenario (Figure 13). The welfare metric provides a comprehensive assessment of whether a policy's benefits through reductions in

environmental damages outweigh the costs of distorting economic behavior. It is sensitive to assumptions on the marginal external cost of driving related externalities and, as with the rest of the analysis, assumptions on the price responsiveness of fuel use and driving and EV prices.

The combined efficient road user charges and energy taxes result in net welfare benefits of around 0.4 percent of GDP per year, equivalent to over USD 15 billion or 7 percent of annual transportation costs. By design, this policy results in the highest welfare gain since marginal private and social costs of environmental harms are equalized so all opportunities to reduce environmental damage are taken as long as the societal benefits of doing so exceeds the private costs. Efficient road user charges increase welfare by slightly less due below optimal pricing of pollution. The partial reform of road user charges and energy taxes generates around twothirds of the welfare benefits of full pricing, but with less impact on energy prices and driving costs.

The welfare impacts of other policies are relatively small, with the exception of the EV subsidy. Maintaining the domestic carbon price slightly increases welfare, mostly through reductions in driving externalities, and has the additional benefit of generating revenue of around 0.1 percent of GDP. The feebate results in a very slight decline in welfare due to a slight increase in the incentive to reduce pollution relative to existing policies, given that the existing incentive is slightly above efficient levels. Increased EV subsidies generate welfare losses of 0.10 percent of GDP (~2 percent of annual transport costs) since economic distortions caused by the higher subsidy far outweigh the benefits of reduced pollution.



Distributional and Other Considerations

Managing the distributional implications of reform are especially important to garner political support and promote equity, but additional analysis is needed to understand distributional impacts. The welfare impacts displayed in Figure 13 relate to economy-wide welfare but there will be some households and firms that benefit more and others who benefit less (or are harmed). For example, those who drive more and do not have low-cost options to reduce driving levels, such as households who live far from their place of employment and find it

costly to relocate, may be made worse off through the introduction of road user charge unless they can easily avoid driving on congested roads. Redistributing (a portion of) the gains to vulnerable households made worse off, as well as carefully communicating and phasing in policy reform, can support political acceptability and equity. A comprehensive analysis of distributional impacts, which may require collecting novel locationally data on distance travelled by household and firm categories, is needed prior to the introduction of road user and congestion charges.

Still, some lessons can be learned from the literature on the distributional impacts of distance and congestion charges, although findings indicate that the incidence of these policies is highly context specific. Road user charges are similar to fuel taxes, expect that they cannot be reduced through improvements in fuel economy— if wealthier households drive more fuel-efficient vehicles, then distance taxes are progressive relative to a fuel taxes. The distributional impacts of congestion charges depend on the abatement costs (which may be lower for high skilled workers given the rise of remote work and more flexible working hours); the policy design (e.g., whether rates vary across hours of the day); access to public transportation; and proximity to work and preferred leisure and social activities. Empirical studies find that the Gothenburg and Stockholm congestion charges are (slightly) regressive before revenue use but there is large variation within income groups. Ex-ante studies find the incidence of distance based vs. fuel taxes to be is mixed and congestion charges are generally regressive before revenue recycling (Denne et al 2020). For both schemes, the way in which revenues are spent is likely the main determinant of the incidence—means-tested subsidies for public transit, cash transfers, and promoting public transport accessibility, with targeting based on exposure to congestion charges (e.g., living or working within the congestion charging area) can help alleviate regressivity impacts. See Lindsey et al 2023 for a literature review, including a review of political economy considerations.

A side benefit of reducing emissions through less driving, rather than increased EV sales, is that it provides less strain to the electricity grid (Figure 14). As the vehicle fleet transitions to EVs and demand for other technology powered by electricity grows (e.g., data centers and heat pumps), electricity use may grow substantially. Under current policies, electricity demand from road transportation is projected to grow to from 4 terawatt hours (TWh) in 2023 to 31 TWh in 2030, while demand only reaches 20 TWh under the road user charge and energy tax policies but increases to nearly 40 TWh with the increased EV subsidy. This compares to total national electricity use of around 450 TWh in 2023. Complementary policies, such as promoting smart metering, real-time electricity pricing, and demand side management, can also support grid resilience and reduce needed capacity additions as electricity demand grows.



Policy Conclusions

The first-best policy of efficient road user and congestion charges and energy taxes provide a range of fiscal and environmental advantages. They reverse the decline in revenue from road transportation but the fact that taxes apply to both EVs and ICEVs (since both vehicle types generate congestion, road damage, and accidents) slows the transition to passenger EVs. The environmental benefits far exceed the economic costs, by 0.4 percent of GDP and 7 percent of annual transportation costs. Road transportation emissions decline to 80 Mt by 2030, meeting the SGPE 2023 target and achieving the provisional medium-term carbon budget. Complementary policies, like the existing means-tested subsidies for EVs and a more stringent feebate could help reduce risks of not meeting carbon budgets, although subsidies would have negative welfare and fiscal impacts. These policies should be phased-in following significant consultation and policy analysis, including to understand and create strategies to address distributional impacts.

Given the benefits of road user and congestion charges, it is important to begin building the associated administrative capacity and consider proxy distance charges in the interim. From an economic efficiency perspective, road user charges would ideally rely on GPS data to provide real-time fees per km based on congestion, vehicle axle weight, and vehicle pollution characteristics, coupled with incentives for auto insurance to switch to pay as you drive premiums rather than payments disconnected to driving distances. However, more practical options exist, including to address privacy concerns and align with EU privacy laws (although coherence with privacy laws is not assessed here)—for example, a road user charge for passenger vehicles based on odometer readings and coupled with high frequency tolling on regularly congested roads and rates that increase during peak hours (e.g., as is in done Santiago, Chile) would likely provide most of the benefits without additional complexity. The road user charge could be applied through an annual registration tax scaled based on distance driven over the past year or regular pre-payments for additional kilometers.²⁹ In the meantime, government could begin building the necessary administrative capacity (e.g., time, location, and driver/vehicle specific estimates of the per km fees), as well as sensitizing the public to changes in the way that driving is priced.

²⁹ There are some examples of existing schemes that charge vehicles per distance driven, including New Zealand, which varies payments by vehicle weight and fuel type, is payable online or manually, and verified using odometer readings; Oregon, which charges a fixed amount to passenger vehicles that opt-in and is paid quarterly with the option of using GPS or odometer readings; and Utah, which charges a fixed amount per electric vehicle using GPS and digital payment technology.

Transitioning the existing bonus/malus to a linear feebate provides a practical, short-term reform with fiscal and environmental benefits. The main benefits of the feebate relative to the existing malus/subsidy scheme are that the feebate improves cost effectiveness through providing the same marginal incentive to reduce emission intensity across the full range of vehicle purchases (whereas the existing feebate only targets those above 118 g per km and in a highly non-linear way, Figure 4) and the feebate's pivot-point can be more easily legislated to automatically achieve revenue-neutrality.^{30,31} which also helps avoid annual political discussions around the

existing malus' pivot point The linear feebate would reduce taxes on highly polluting ICEVs, increase taxes on those just above the pivot point, and increase subsidies for low emissions ICEVs (Figure 15)-if the reduction in taxes on highly polluting ICEVs is undesirable then a surcharge on such vehicles or a stronger feebate could be considered, at least during a transitionary period. Compared to a policy where EV subsidies are phased out between 2025 and 2035, a feebate of €250 per ton would result in slightly lower emissions in 2030 and generate an estimated fiscal savings of €3.2 billion (0.1 percent of GDP). Practically, the design of a feebate for heavy goods vehicles (and potentially light commercial vehicles) would need to consider a more complex value chain, where freight companies may



assemble trucks themselves after separately purchasing an engine, a vehicle, and a trailer. Since tailoring a feebate to each of these components is likely unfeasible, the feebate could be converted into an annual circulation tax/subsidy scheme for this segment.

Means-testing and additional environmental components could complement a linear feebate. To promote equity, the feebate could be combined with an additional means-tested EV subsidy that is either funded through making the feebate slightly revenue raising (by setting the pivot point below what is needed to achieve revenue-neutrality) or the general budget; and to account for the additional local pollutants from diesel vehicles, an additional charge could be levied according to the vehicle's Euro class (e.g., Austria, Belgium, Greece, Slovenia; see <u>ACEA 2022</u> for details). If separately applied to heavy goods and light commercial vehicles at the same shadow carbon price (after accounting for the impact of EU fuel economy standards) as passenger vehicles, the feebate would also help equalize abatement costs across vehicle categories, promoting more efficient emissions reductions in the road transportation sector.

³⁰ The existing bonus/malus is not intrinsically revenue losing, but is under the current design given that the malus does not apply to most vehicle sales (given the high pivot point) and it's large penalty on high-emitting ICEVs significantly erodes the tax base the latter may be seen as an advantage of the bonus/malus but does likely lead to high abatement costs.

³¹ The feebate pivot point resulting in revenue neutrality would need to be studied using data on the distribution of emissionsintensity of vehicle sales in France—if sales normally distributed, then a pivot point set at the average emissions-intensity will be approximately revenue neutral, but the distribution is likely skewed due to growth in zero-emissions vehicles.

Gradually increasing the domestic carbon price and applying it as a price floor when the EU ETS II is introduced would increase revenue, reduce emissions, and provide valuable price certainty.³² If the current carbon price is slowly increased to €90 per ton by 2030 and implemented as a price floor for the EU ETS II, road transportation emissions would decline by 2.5 percent and revenue increase by 0.1 percent of GDP by 2030. This would also reduce the volatility of the ETS price, which can be subject to unpredicted and large swings, to improve political acceptability and reduce abatement costs.³³ The fiscal and environmental benefits may be offset by political sensitivities around increasing fossil fuel prices, although recycling a portion of the revenue in a well-targeted manner can more than counteract adverse impacts to specific households and firms. Coordination with neighboring EU countries could also be considered—since aggregate EU emissions are reduced at the least cost when the carbon price is equivalent across countries, it may make sense to coordinate with other large, neighboring emitters on whether to remove domestic carbon prices from EU ETS II sectors, keep taxes and receive an exemption from the EU ETS II (as allowed under <u>Article 30e.3.</u>), or keep both domestic and EU-level carbon prices and, ideally, have equivalent price floors.

Increasing EV subsides should be limited to very targeted cases, as their fiscal costs and economic distortions grows as the price of EVs fall. These conclusions support the existing policy trend for EV subsidies, which have been increasingly targeted according to income and other household characteristics, such as living in a low-emissions zone or far from work. Doubling broad-based subsidies leads to revenue loss of 0.4 percent of GDP by 2030 and increased economic efficiency costs and driving related externalities.

Conversely, subsidies to reduce EV production costs promote positive externalities and help achieve climate objectives but need to be well designed to ensure cost-effectiveness. The EV supply chain and technologies are still being developed but progress could be at below efficient levels without subsidies since there are possible network externalities and other spillovers that have benefits not captured by investors/innovators. However, if subsidies are not well designed, they can provide support to activities that would take place without the subsidy, leading to spent fiscal resources without reducing emissions—the Netherlands SDE++ provides an example of a subsidy scheme that reduces this risk by auctioning subsidy support to investments with the lowest decarbonization costs but does require substantial administrative and compliance efforts.

As indicated by the focus of the paper, market-based measures should form the centerpiece of reform for efficiency and fiscal reasons but can be complemented by other policies, such as those to encourage teleworking and further modal shifts. Road user and congestion charges and fuel taxes are most efficient in controlling driving-related externalities at the lowest cost since they equate marginal and social incentives, but achieving efficient price signals does require politically difficult cost increases. Supporting measures, in addition to expanding public transportation,³⁴ can help close remaining emissions gaps and improve equity. Exemptions can support political acceptability but should be designed carefully—for example, congestion charges that exempt EVs may encourage the shift away from ICEVs but struggle to reduce congestion. There is also a role for incorporating green considerations into government procurement through the use shadow carbon pricing

³² Half of the revenues from the EU ETS II are earmarked for a Social Climate Fund, which is intended to support vulnerable households and small business, and the other half to national budgets but earmarked for climate measures.

³³ For example, one study found that price uncertainty under an ETS increases marginal abatement costs by 15 percent (Fell, MacKenzie, and Pizer 2012). Similar to the existing EU ETS, the EU ETS II has mechanisms to reduce price volatility, including a fixed price for the initial years, and it is unclear if the ETS II will exhibit similar volatility to the existing ETS.

³⁴ Public transport can also enhance the short-term effectiveness of pricing policies by making the targeted activity (e.g., CO2 emissions or congestion) more elastic. For example, see Avner et al 2014.

and to provide producers with certainty over future demand. See Lindsey et al 2023 for some discussion on different regulatory policy options to control congestion.

Conclusion

The analysis finds that, in line with the SGPE 2023, additional policy effort is needed to achieve transportation carbon budgets. Road transportation emissions under current policies are projected to reach 94 Mt by 2030 (a 22 percent reduction relative to 2023 levels) compared to a provisional budget of 75 Mt and a SGPE target of 81 Mt. Most emissions reductions between 2022 and 2030 come from the passenger and light commercial vehicle segment (rather than heavy goods) due to lower decarbonization costs and stronger policy incentives. In 2030, passenger and light commercial vehicles are projected to emit 68 Mt and heavy goods 26 Mt, compared to SGPE targets of 63 and 18 Mt.

Achieving carbon budgets and generating co-benefits requires policies to promote reductions in driving levels, in addition to improvements in the emissions-intensity of vehicles. Current and planned policies tend to encourage switching to EVs (through EV subsidies) and more fuel efficient ICEVs (through the EU fuel economy standard and the malus system), while investments to promote modal shifts and the EU ETS II are the only major planned policy to reduce driving levels. Primarily relying on only one decarbonization lever (improved emissions-intensity) increases economic costs of the transition and leads to more congestion, road accidents, and road damage (DG Tresor 2023 provides similar findings). Analysis in this paper shows that pollution is generally overpriced and driving-related externalities underpriced.

A combination of higher fuel and road user charges produce significant reductions in emissions and environmental co-benefits, while raising revenue.³⁵ A road user charge that internalizes road accident, congestion, and road damage costs, coupled with the provision of public transport, is likely the most efficient way to promote reductions in driving levels—when introduced at efficient levels, road user and congestion charges are estimated to generate annual reductions in driving- and pollution-related externalities of €33 and 7 billion, respectively, compared to economic costs of €28 billion by 2030, and bring emissions in line with carbon budgets. Proxies for real-time road user charges, such as annual registration fees (or prepayment based on documented odometer readings) that vary with driving amounts and the pollution characteristics of vehicles, as well as tolling on congested roads, could serve as interim measures while the government builds administrative capacity and political support to implement real-time, road user charges.

Road transportation policies must also consider the projected decline in fiscal revenue, which is estimated to fall by about 0.6 percent of GDP over the next decade. As the vehicle fleet electrifies, revenue from fuel taxes declines due the relatively high energy efficiency of EVs, low taxes on electricity, and subsidies for EVs. Again, transitioning to road user and congestion charges and higher fuel taxes provide benefits as they impact both EVs and ICEVs (albeit with higher charges on ICEVs given their pollution), resulting in a more resilient revenue base and way to control externalities—such policies are estimated to generate revenue of 2.5 percent of GDP annually when applied at efficient levels. A portion of the revenue raised should be used to support vulnerable households and firms, although detailed distributional analysis is needed to well target this support.

³⁵ The impact on driving related externalities more than offsets the resulting overcharging for pollution damages.

Fine-tuning of existing incentives can strengthen the policy package and provide near-term but more marginal benefits. Transitioning from the existing bonus/malus system to a linear feebate, ideally that extends to heavy goods vehicles using a separate tax/subsidy schedule, generates fiscal savings of 0.1 percent relative to existing policies while providing similar decarbonization incentives and automatically adjusting subsidy levels to ensure cost-effectiveness. Gradually increasing the domestic carbon price to €90 per ton by 2030 and applying as a price floor to EU ETS II raises revenue of 0.1 percent in 2030. Subsidies for EV purchases are fiscally costly and a relatively expensive policy to promote decarbonization, although they clearly provide political benefits. The continued refinement of targeting and eventually phasing out, or transitioning to a linear feebate scheme, could help balance fiscal, equity, and environmental objectives.

Annex I. Model Description

A "technoeconomic" model is used to forecast vehicle and driving demand, road transportation energy use, and emissions under various policies. The model performs separate projections for light-duty vehicles (LDVs, cars and commercial vehicles with weight below 3.5 tons) and heavy-duty vehicles (HDVs, medium- and heavy-duty freight) since the two vehicle types have different existing fuel pricing policies, economics, and abatement pathways—for example, HDVs have higher depreciation rates, lower fuel efficiency, more VKT distance travelled, and are more costly to electrify—as well as distinguishing between new and used vehicles given differences in purchase prices and fuel economy and varying reliance on used vehicle markets.

Historical data on fuel demand, fuel economy, vehicle ownership, and fuel prices come from a variety of sources (Table 3). This data is used as inputs into the model and to estimate the total cost of ownership for EVs and ICEVs across vehicle types and for used vs. new vehicles.

Variable	Unit	Value	Source
EV purchase	%	25% (passenger), 7.6% (light), and 6.2% (freight) in	IEA Electric Vehicles Data
share		2023	Explorer
Vehicle ownership	Vehicles per	559 (passenger), 88 (light), and 9.3 (freight) in 2021	OECD's ITF for passenger and
	1,000 people		light, IEA for freight
Fuel economy,	Liters per 100	5.4 (passenger), 14.24 (light), and 33.72 (freight) in	IEA Fuel Economy Initiative
average	km	2019	
Fuel economy,	Percent	20 percent below average (passenger, light) and 10	EEA for passenger, based on fuel
new ICEV		percent below average (freight)	economy standards for freight
Fuel economy,	kWh per 100	14.24 (passenger) in 2019; 76 (light) and 150 (freight)	IEA for passenger and ICCT for
new EV	km	in 2020 with future decline	freight and light
Share of first-time	% of vehicle	46 percent of vehicles (all vehicle types) in 2021	Estimated using International
used vehicles	stock		Road Federation WRS
Useful life	years	15 years (passenger and light), 8 years (freight)	Argonne
Fuel consumption,	Billion liters	11 (gasoline, passenger), 18 (diesel, passenger), 4	Enerdata and IEA Energy Efficient
ICEVs		(diesel, light), and 11 bln liters (diesel, freight) in 2022	Indicators
Fuel consumption,	TWh	2.3 (passenger) and 0.006 (freight) in 2022	Enerdata and IEA Energy Efficient
EVs			Indicators
VKT per vehicle	kilometers	13,500 (passenger and light) and 53,000 (freight) in	Inferred from fuel use and number
		2022	of vehicles
Energy prices	USD per liter	2.03 (gasoline, passenger), 1.94 (diesel, passenger),	EU Weekly Oil Bulletin and
(including VAT)	or kWh	1.41 (diesel, freight), 0.22 (electricity, passenger), and 0.14 (electricity, freight) in 2023	Eurostat

Table 3. Historical Data Used in the Model

The total lifecycle cost of ownership (TCO) of light- and heavy-duty vehicles is the key determinant of switching from ICE to EVs. TCO is calculated as a net present value (NPV) per-kilometer cost of using a vehicle over its lifetime and is separated into the purchase price (adjusted for depreciation), insurance, maintenance, fuel costs, and taxes on driving.

- The purchase price of a new vehicle is a function of the following:
 - Retail prices—for ICEs these are projected to remain constant in the baseline for a given income level but increase with rising fuel economy (induced by higher fuel prices, feebates, standards, etc.) in the policy scenario and as income rises. Retail prices for EVs fall steeply with declining battery costs for both light-

and heavy-duty EVs but increase as income rises.³⁶ Pre-tax vehicle purchase price data for passenger vehicles comes from the French authorities and freight from the ICCT. Prices are shown in **Figure 16**.

- Depreciation—which is faster for freight vehicles due to their (much) higher annual mileage (i.e., faster fleet turnover) and faster in the first year of vehicle ownership, reflecting the sharp decline in resale value after vehicle purchase (Argonne 2021). Depreciation rates are assumed to be the same for EVs and ICEVs.
- Salvage or resale value—the resale value reduces the cost of ownership and is the vehicle's estimated
 market value at the end of the ownership period. This is equal to the depreciated value of the vehicle, with
 an adjustment to reflect changes in the retail price of new vehicles relative to the retail price of the vehicle
 entering the used car market—this adjustment reduces the resale value of EVs since newer vehicles are
 relatively cheap due to declining costs.
- Discount rates—discount rates are needed to value costs across the vehicle's lifecycle. Generally, EVs have higher upfront costs (e.g., retail prices) but lower future costs (e.g., fuel and maintenance) than do ICEs so a higher discount rate, which reduces the value of future cost savings, increases the relative costs for EVs. The discount rate for LDVs and HDVs reflect households' and firms' cost of capital, respectively—the former is assumed to be the risk-free discount rate, rather than financing costs, since the discount rate is used to discount economic depreciation, rather than the vehicle purchase price or financing costs.
- Taxes on vehicle purchases—these include any modelled subsidies, feebates and existing countryspecific VAT and customs for passenger vehicles. Fuel efficiency standards are modelled as a shadow carbon price.
- *Range anxiety*—an additional cost for EVs that declines over time and as charging station availability grows, reflecting anxiety over charging availability, range limitations, and other non-financial costs related to EV ownership, such as consumer knowledge. Range anxiety is calibrated so that new vehicle sales in 2023 match actual values.³⁷
- Maintenance costs vary with labor costs (measured by wage rates) and are lower for EVs than ICEVs due to fewer moving parts for the former.
- Insurance is assumed to be the same for EVs and ICEVs.
- Fuel costs (from gasoline, diesel, or electricity) are a function of VKT, fuel economy, and fuel prices. Each calculation is performed separately for gasoline and diesel LDVs and then a weighted average is taken, based on ownership shares.
 - Fuel prices—see Table 3 for post-tax fuel prices in 2023. An additional mark-up is applied to electricity
 prices to cover charging infrastructure costs, which decline with technological improvements and EV
 deployment expansion (the latter increasing charging station utilization and, thus, reducing the fixed cost
 of charging infrastructure).

³⁶ The positive income elasticity of retail prices reflects that people buy larger, safer, and more expensive cars in wealthier countries. ³⁷ The relationship between range anxiety and the availability of charging stations is calibrated to mimic elasticities in Cole et al

^{2021.} A 10 percent increase in charging availability increases EV uptake by 3.7 percent at relatively low levels of charging availability. The elasticity of charging station supply to charging station costs is assumed to be 0.67 (Cole et al 2021). For simplicity, only fast charging stations are modelled.

- Fuel economy—this increases exogenously with technological improvement in the baseline for all vehicles and, additionally, with learning-by-doing and economies of scale for EVs. For light- and heavy-duty ICEVs fuel economy improves 1 and 2 percent a year respectively from gradual autonomous improvement, while heavy-duty EVs improve from 0.7 km per kWh in 2020 to 1.5 km per kWh in 2050. In addition, fuel economy of new EVs and ICEVs increases with higher fuel prices as manufactures make technological modifications and vehicle buyers shift to more fuel efficient models—elasticities of -0.4 and -0.3 are assumed for light- and heavy-duty ICEVs (see Black et al. 2023c). The fuel economy of EVs is assumed to decline exogenously but not in response to changing prices given that high efficiently.
- VKT—the VKT per new vehicle adjusts to fuel prices and distance-based charges according to driving elasticities (-0.3 and -0.2 for light- and heavy-duty vehicles respectively) and to income levels (elasticity of 0.05).³⁸ VKT per vehicle is capped using a cross-country regression of wealthy countries with urbanization rates and population density as independent variables. It is assumed that VKT per vehicle is identical for ICEVs and EVs for new vehicles given that existing empirical research is mixed.
- For used, vehicles, the purchase price is equal to the salvage value of a newly purchased vehicle and fuel economy is the lagged values for new vehicles.

	ICE – passenger	EV – passenger	ICE – freight	EV – freight
New vehicle	See Figure 16			
purchase price				
Depreciation	30% in first year and then linearly depreciated over 30% in first year and then linearly depreciated over 8			
	14 years, sold	14 years, sold at 7 years for new cars; used years, sold at year 5; used vehicles are held until		
	vehicles a	are held until retirement	retirement	
Range anxiety	NA	EUR 6,000 in 2023	NA	EUR 240,000 in 2023
Fuel/energy	1% annual	Country-specific for around 30	exogenous	150 to 100 kWh per 100 km
efficiency	exogenous	countries (IEA), average for	improvement of	from 2020 to 2030 (ICCT) and
	improvement	others, 1% annual exogenous	2.5% per year	continued, linear improvement
		improvement	(ICCT)	after 2030
Maintenance	\$0.06 per km	1/3 of ICE (Argonne)	\$0.125 per km	1/3 of ICE (ICCT)
	(Argonne)		(ICCT)	
Insurance	1.5% of vehicle value (Argonne) \$0.04 per km (ICCT)			
Discount rate	2.5% (passengers, Argonne) and 5% (freight)			
Sources: ICCT refers to its Basma et al. 2021 and Sharpe and Basma 2022, Argonne refers to its Burnham et al. 2021. Notes: all				
prices are presented in 2023 real terms. For freight vehicles purchase costs, the average of straight trucks and tractor trailers is				
used.				

Table 4. Total Cost of Ownership Parameters

³⁸ The distance driven elasticities are similar to that found in a France specific study (Odran et al 2023), which found short-term elasticities of -0.21 to -0.38 for households. The study found slightly lower elasticities for the 2nd and 3rd quantiles.



TCO estimates for each vehicle type are used to allocate new vehicle demand across vehicle types with the following steps. Total vehicle demand is estimated using the Gompertz function (e.g., see <u>Dargay et al 2006</u>), with population and GDP projections from the IMF WEO, and vehicle additions are equal to the difference between total demand and ownership after depreciation and used cars sold domestically. A logit function based on the relative TCO of ICE and EV vehicles determines the share of vehicle demand met by ICE vs. EV vehicles, separately for new vs. used vehicle purchases. The logit function is fitted to minimize the difference between modelled and actual EV sales between 2015 and 2023 for select economies.^{39,40} The availability of used EVs (both those that are previously owned domestically and imports) is constrained based on new vehicles that are reach the end of the initial ownership period.

Once the vehicle stock is estimated for a given year, driving distances are adjusted according to changes in the post-tax marginal cost of driving and driving elasticities and changes in income per capita. The resulting information on size and disaggregation of the vehicle stock and distance driven per vehicle allows for estimation of fuel use, fiscal revenue, and emissions.

The impact of congestion charging requires additional assumption. The elasticity of congestion to congestion charges is -0.6 (-0.75 for passenger vehicles and -0.1 for heavy goods, given higher value of time for firms), which is in line with the average of peak time elasticities in Stockholm and Gothenburg at the time of congestion pricing introduction (Denne et al. 2020).⁴¹ Driving only increases by half of the reduction in congestion since some vehicles re-route to other roads and congestion levels increase exponentially to traffic levels (e.g., emissions in Stockholm fell by about half as much as congestion declined). Congestion charging is assumed to apply to 12 percent of driving, which is the portion of driving that occurs during peak, working hours in France according to TomTom.

³⁹ The k-parameter for the logic function is 3.25 and increases to 4.75 as EV uptake crosses 50 percent, reflecting patterns in countries with high EV uptake.

⁴⁰ Used vehicles are split between imported used vehicles and used vehicles that were previously owned domestically. There is assumed to be a limited supply of both imported and second-hand domestic used vehicles, which is determined based on the global and domestic number of EV purchases from 10 years ago (i.e., the assumed vehicle ownership period) for passenger vehicles and 4 years ago for freight.

⁴¹ The elasticity including non-peak times, which has a lower charge, is -0.88 for Stockholm and Gothenburg and -0.68 across London, Milan, Stockholm and Gothenburg (Denne et al. 2020)

Annex II. Additional Charts

Time-series revenue implications assuming that all policies are introduced immediately (e.g., without a gradual phase-in).



Revenue and emissions implications of varying the level of road user charges and including a congestion charge in 2030.



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Balancing Environmental, Fiscal, and Welfare Impacts of Transportation Decarbonization in France Working Paper No. WP/2024/145