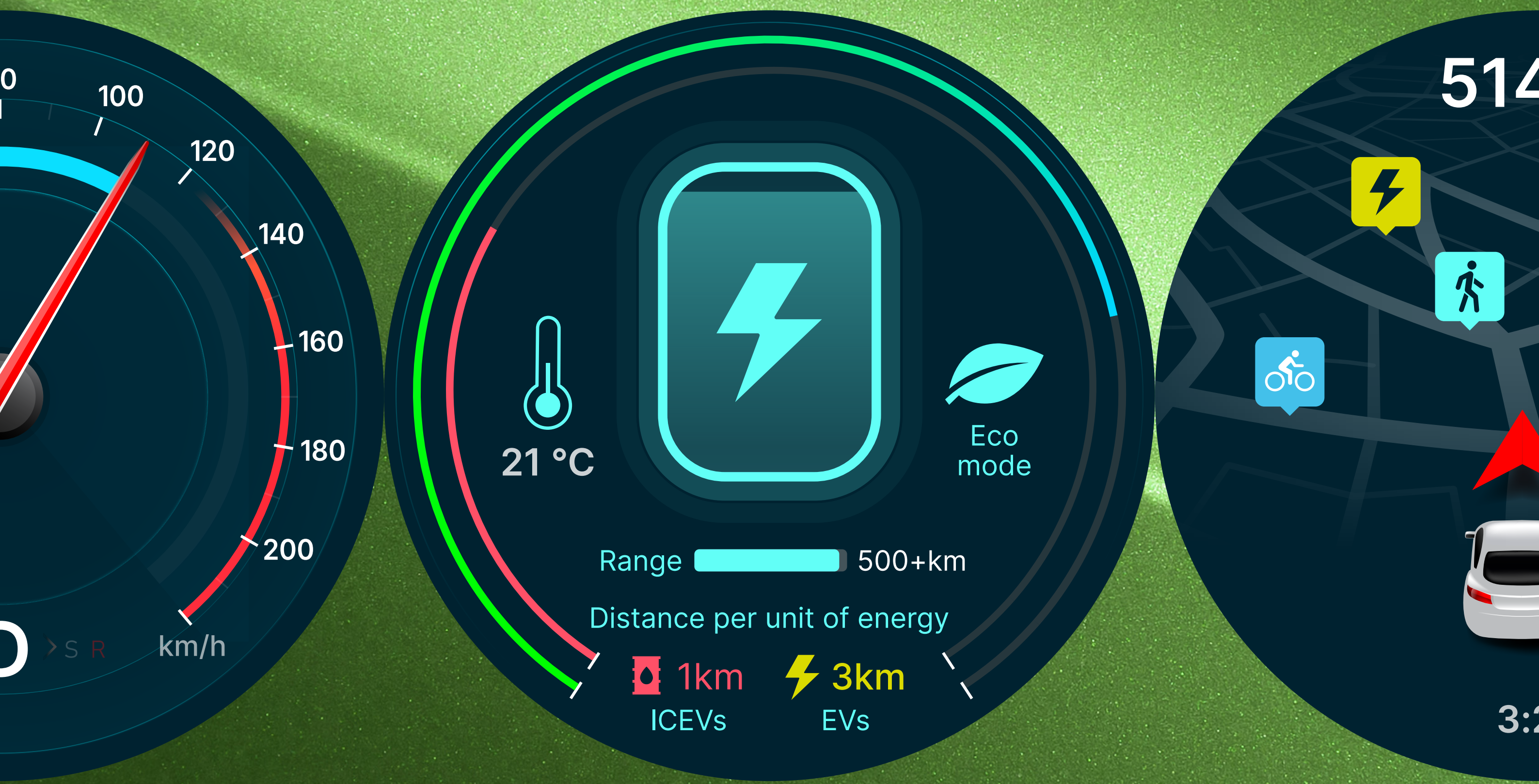
The Road Ahead:

Electrification, Design and Mobility Choices for Efficient Transport

December 2025 | Version 1



Energy Transitions Commission

Insights Briefing

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C.

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. The ETC is chaired by Lord Adair Turner who works with the ETC team, led by Faustine Delasalle (Vice-Chair), Ita Kettleborough (Director), and Mike Hemsley (Deputy Director).

The ETC's *The Road Ahead: Electrification, Design and Mobility Choices for Efficient Transport* briefing was developed in consultation with ETC Members, but it should not be taken as members agreeing with every finding or recommendation. This report examines energy productivity improvements in the road transport sector as a critical pathway to net-zero emissions, highlighting the role of electrification as the primary driver of energy efficiency alongside complementary efficiency measures. The ETC team would like to thank the ETC members, member experts and the ETC's broader network of external experts for their active participation in the development of this briefing. The ETC partners with Bloomberg New Energy Finance (BNEF) for leading market information. All BNEF data has been sourced from about.bnef.com.

The ETC Commissioners not only agree on the importance of reaching net-zero carbon emissions from the energy and industrial systems by mid-century but also share a broad vision of how the transition can be achieved. The fact that this agreement is possible between leaders from companies and organisations with different perspectives on and interests in the energy system should give decision-makers across the world confidence that it is possible simultaneously to grow the global economy and to limit global warming to well below 2°C. Many of the key actions to achieve these goals are clear and can be pursued without delay.

This report should be cited as: ETC (2025), *The Road Ahead: Electrification, Design and Mobility Choices for Efficient Transport*. The report is part of our workstream on energy productivity which examines the total economy-wide opportunity for efficiency across major sectors.

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Front cover and Report design: Burnthebook.

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Introduction

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1.1 Improving energy productivity: The economy-wide challenge

To achieve a net zero-carbon economy by mid-century, the world must ensure that by then all energy use vastly reduces its CO_2 and other greenhouse gas (GHG) emissions. This will require primarily switching to the use of non-fossil fuel energy sources, but also the offsetting of a small residual use of fossil fuels by carbon capture and storage (CCS). Much of the work of the Energy Transitions Commission (ETC) has therefore been devoted to identifying how to achieve this decarbonisation of energy supply.[1]

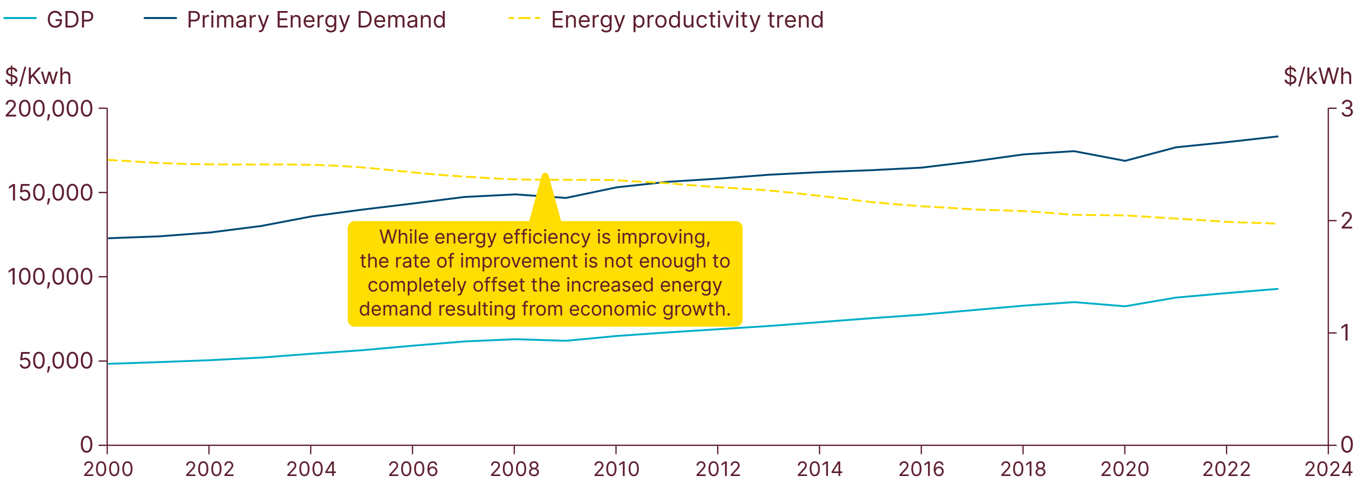
Emissions could also be reduced – and reduced faster - by using energy more efficiently. Furthermore, even with all energy supply decarbonised, greater energy efficiency could still play a critical role by reducing the total cost of energy inputs required. Improving overall "energy productivity", i.e. how much energy input is required to deliver a given level of human welfare, is therefore an important objective. This is conventionally measured as $ of GDP per energy input (in kWh).[2] Over the last ten years, global primary energy productivity improvements have increased on average by 1.7% per annum. However, with global GDP growing at 2.7%, overall energy demand has continued to grow [Exhibit 1.1]. At COP28, nations agreed to double energy productivity improvements, achieving a global average of 4.1% per annum by 2030.[3]

The ETC believes that to identify how this energy productivity improvement could be achieved, and to assess the long-term potential for improvement beyond 2030, it is essential to take a detailed sector-by-sector approach. The ETC therefore conducted an analysis of productivity improvement potential

Exhibit 1.1

Despite energy intensity declining, primary energy demand growth indicates energy intensity improvements have lagged behind GDP growth

Total GDP vs. Primary energy demand, 2000–2023
GDP in constant 2015 $ billion, Primary Energy Demand in TWh; Energy intensity in constant 2015 $ / kWh



SOURCE: Systemiq analysis for the ETC; World Bank Group (2021), *Key World Energy Statistics 2021,* available at https://www.iea.org/reports/key-world-energy-statistics-2021/final-consumption. [Accessed 10/08/2024]; Our World in Data (2020), *Energy Production and Consumption,* available at https://ourworldindata.org/energy-production-consumption. [Accessed 10/08/2024]; IEA (2023), *Energy Efficiency 2023.*

1 ETC (2024), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

2 An alternative measure sometimes used is the "energy intensity" of GDP, given by kWh of energy use per $ of GDP: This is the inverse of energy productivity.

3 COP28 target uses as baseline 2022 energy improvement. See COP28, UEA, Global Renewables and Energy Efficiency Pledge, available at https://energy.ec.europa.eu/system/files/2023-12/Global_Renewables_and_Energy_Efficiency_Pledge.pdf.

across major sectors (road transport, buildings and key industries) and identified policies required to seize this potential over the past year. *The Road Ahead: Electrification, Design and Mobility Choices for Efficient Transport* sets out our analysis of energy productivity improvement in the road transport sector, with a detailed focus across specific levers. We have also published an insights briefing aggregating the sectoral opportunities into an assessment of the total economy-wide opportunity.

In addition to identifying energy productivity potential by sector, it is also vital to consider the several different types of improvements that could together deliver enhanced energy productivity. Exhibit 1.2 sets out a framework for energy productivity (e.g., reduced kWh of energy input per $ of GDP) which is resulting from:

- **Energy process efficiency**, delivering a given quantity of a specific service with less energy input (e.g., fewer litres of jet fuel per aviation passenger km).
- **Service efficiency**, which enables people to enjoy the same standard of living but using less energy-intensive services or products (e.g., reduced road or air passenger km but increased rail). It is divided in two sub-categories: demand efficiency and product efficiency.
- **Material efficiency**, delivering a given quantity of products with reduced material inputs (e.g., fewer kilos of steel or plastics per passenger vehicle).

Our final report on overall energy productivity assesses the combined potential across all of these categories for all sectors. In this report, we focus only on energy process efficiency, and service (demand and product) efficiency. Opportunities to improve material efficiency by minimising mineral and other inputs into vehicle batteries (whether via new technology development or recycling) were considered in depth in our 2023 ETC report on *Material and Resource Requirements for the Energy Transition*. Material efficiency, although not the focus of this report, should remain a priority for original equipment manufacturers (OEMs) and policymakers.

It is also important, in analysing energy productivity improvements, to distinguish between "final energy demand" and "primary energy demand" [Box A]. Final energy demand measures energy inputs at the point of use (e.g., the chemical energy in the petrol put into a vehicle fuel tank vs. the electricity put into an EV battery); primary energy demand also captures any energy lost in the process of production of usable final energy (e.g., conversion losses in oil production and refining, or losses involved during electricity generation).

In some cases, actions that reduce final energy demand could increase primary energy demand (e.g., if an electrified process were powered by electricity generated inefficiently from fossil fuels);

Exhibit 1.2

Using the ETC energy productivity framework, we will assess possibilities to increase energy efficiency in the road sector

Target figure	Key lever	Guiding question	Reduced quantity	Example
Energy Productivity (energy input per living standards) =	Energy process efficiency ×	How can we decrease the energy input per (production) process?	Process energy	Shift to less energy-intense production technology, incremental energy efficiency increase
	Service efficiency: Demand efficiency ×	How can we decrease the demand without sacrificing living standard?	Demand (for specific service)	Behaviour changes e.g., switch to train journey instead of airplane
	Service efficiency: Product efficiency ×	How can we increase the utilisation of the product?	Product	Reuse, sharing of products, increased product lifetime (e.g., car-sharing/ car-pooling)
	Material efficiency	How can we decrease the material input per product?	Material	Recycling and use of recycled content, reduce primary material use while maintaining specs of product

SOURCE: Systemiq analysis for the ETC.

Box A

Defining and comparing primary and final energy demand

There are four key ways of measuring energy. These metrics capture the transformations and losses that occur across the energy chain. The differences between the first stage ("primary energy") and the last ("useful energy") can be very large:[4]

- **Primary energy:** Primary energy is energy available as resources – such as the fuels that are burnt in power plants – before it has been transformed. This relates to coal before it has been burned, uranium for nuclear power or barrels of oil before it has been processed into gasoline.
- **Secondary energy:** When we convert primary energy into a transportable form we speak of secondary energy. For example, when we burn coal in a power plant to produce electricity, electricity is a form of secondary energy. Secondary energy includes liquid fuels (such as gasoline and diesel – which are refined oil), electricity, and heat.
- **Final energy**: Once we've transported secondary energy to the consumer we have final energy. Final energy is what a consumer buys and receives, such as electricity in their home, heating or petrol at the fuel pump.
- **Useful energy**: This is the last step. It is the energy that goes towards the desired output of the end-use application. For a lightbulb, it's the amount of light that is produced. For a car, it's the amount of kinetic (movement) energy that is produced.

and in some cases, measures of supply-side decarbonisation could increase primary energy use while still reducing emissions (e.g., shifting from conventional jet fuel to bioenergy or synthetic sustainable aviation fuel).

In this road transport analysis, and in all the sector analyses that will contribute to our overall report, we identify how specific actions will impact both final and primary energy demand, and therefore emissions, and the implications for policy.

4 Our World in Data (2022), *Primary, secondary, final, and useful energy: Why are there different ways of measuring energy?*

Finally, as context for this report, Box B explains the two reference scenarios that the ETC has developed to describe the possible future evolution of the global energy system. These are labelled Accelerated but Clearly Feasible (ACF) and Possible but Stretching (PBS). The former is broadly compatible with limiting global warming to 1.7°C, the latter with a roughly 50% chance of limiting global warming to 1.5°C. These scenarios reflect an internally consistent set of assumptions about the growth of demand for energy-using products and services, the pace of supply-side decarbonisation by different sectors, and the potential for energy productivity improvement.

In this report, we use the ACF scenario as our base case, and assess both the actions required to deliver the pace of energy productivity improvement assumed in that scenario, and the opportunities to achieve still faster progress.

Box B

Starting point of the analysis

In our 2023 report *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels*, the ETC presented two scenarios outlining future fossil fuel demand and delineated the essential policies to achieve these trajectories:

- **The *Accelerated but Clearly Feasible scenario* (ACF).** This scenario is clearly technically and economically feasible, but in some sectors will require more forceful policy support than is currently in place.[5] If combined with significant carbon removals, this scenario would be compatible with limiting global warming below 2°C (specifically to 1.7°C), but would not deliver a 1.5°C limit.
- **The *Possible But Stretching scenario* (PBS)**, is also technically and economically feasible, but would require significant strengthening of current commitments and policies. Combined with significant carbon removals, this scenario would come close to delivering a 50% chance of limiting global warming to 1.5°C in 2050, and a level below 1.5°C in 2100 if removals could continue in the second half of the century.

1.2 Energy productivity in road transport: Base case assumptions and structure of the report

The road transportation sector — including cars, buses, trucks, and two-and-three-wheelers — accounts for about 6.4 Gt of CO_2 emissions, which is over 12% of global GHG emissions.[6]

These emissions are produced by 1.4 billion passenger cars, 1.3 billion two-and-three-wheelers, 200 million light and medium commercial vehicles, and 40 million heavy commercial vehicles.[7] In total, these vehicles currently consume the equivalent of 43 million barrels of oil per day (Mb per d) – out of a global annual oil consumption of around 102 Mb per d and 255 TWh of electricity per year – a growing but small share of a global annual electricity consumption of around 29,000 TWh.[8]

Over the next three decades, both vehicle numbers and km travelled will increase significantly, in particular in developing countries. Total passenger and freight km travelled could grow by 1.9% per annum and 2.4.% per annum respectively [Exhibit 1.3]. Within our ACF scenario, passenger vehicles could increase to 1.8 billion, two-and-three-wheelers to 2 billion, light and medium commercial vehicles to 415 million, and heavy commercial vehicles to 75 million [Exhibit 1.4].

The falling costs of batteries, and electric vehicles, mean that electrification provides the means to meet this growing road transport demand in an eventually zero-carbon fashion. For example in China, 1 in every 2 new vehicles sold is now electric, with EVs now cheaper to purchase than many fossil fuel equivalent models. Based on a switch to EVs, **our ACF scenario suggests that total road transport oil demand could fall to 6 Mb per d by 2050, while electricity use increases to 8,000 TWh by 2050** [Exhibit 1.5].

Even in this scenario, however, oil use between now and 2050 would produce about 114 Gt of cumulative emissions, while cumulative electricity use, given the still high carbon intensity of much electricity production (as seen in Grid CO_2 intensity in Exhibit 1.6), could result in around 14 Gt of cumulative emissions, leading to a combined 128 $GtCO_2$ equivalent to over 3 years of total global annual CO_2 emissions [Exhibit 1.6].

5 Technically feasible implies that demand reductions can be delivered by technologies that are already known and being deployed, even if only on a small scale today. Economically feasible implies that demand reductions can be delivered with limited impacts on prices and thus living standards (relative to business-as-usual) and thus politically feasible.

6 6.4 $GtCO_2$ emissions out of a budget of 52.8 $GtCO_2$ according to ETC (2024), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.* Aligned with Our World in Data (2016), *Global greenhouse gas emissions by sector.*

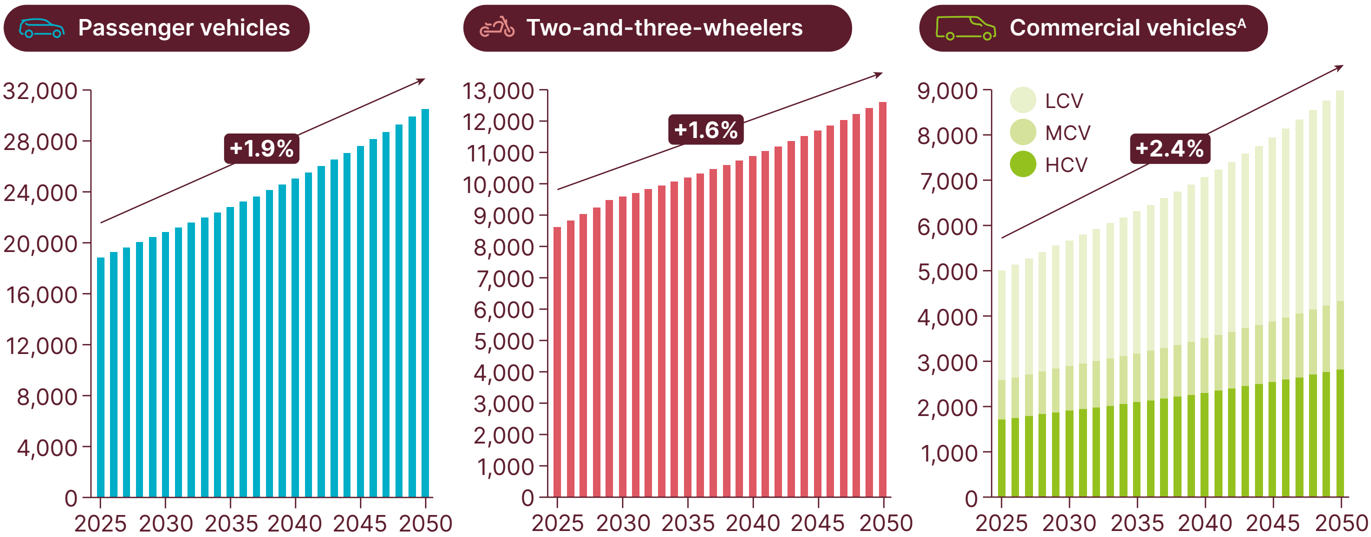
7 ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

8 The combustion of a barrel of oil equivalent results ~405 kg CO_2 according to the IEA (2023), *Emissions from Oil and Gas Operations in Net Zero Transitions.* Ember (2024), *Global Electricity Review.*

Exhibit 1.3

Passenger demand for transport is expected to grow by 1.9% annually, with commercial vehicles increasing by 2.4% annually

Demand for passenger km and freight transport km in the ACF scenario
Billions of km



NOTE: (A) Commercial vehicles include light, medium and heavy commercial vehicles (LCV, MCV, HCV); ACF = Accelerated but Clearly Feasible Scenario.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

Exhibit 1.4

Fleet continues to grow to 2050, with increased electrification

Stock of vehicles in the ACF Scenario
Millions of vehicles

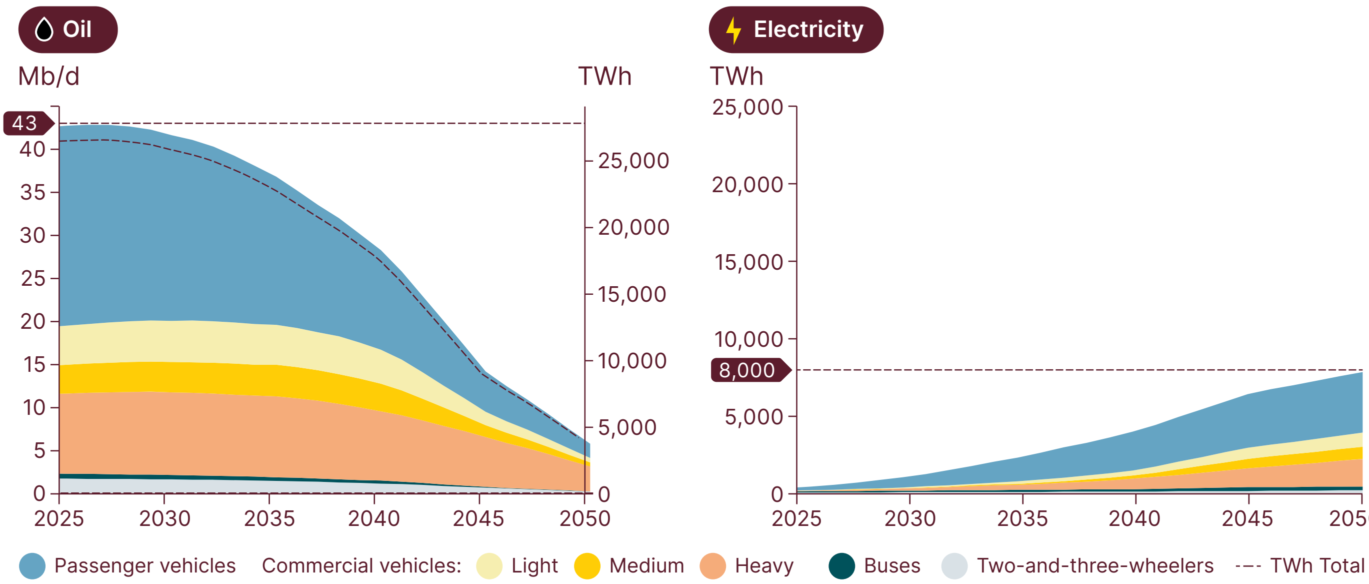
NOTE: (B) Commercial vehicles include LCV, MCV and HCV and both EVs and FCEVs. ACF = Accelerated but Clearly Feasible (ACF) Scenario.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

Exhibit 1.5

Widespread vehicle electrification will cause a dramatic reduction in oil demand, with a significant increase in electricity demand

Oil and electricity demand for road transport in the ACF scenario



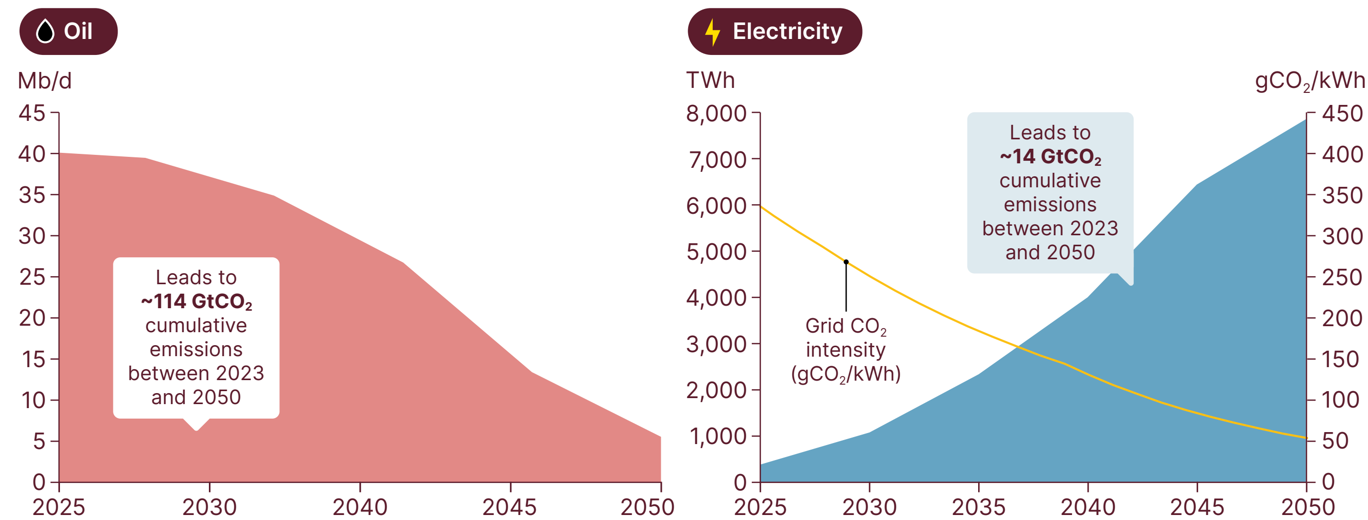
NOTE: ACF = Accelerated but Clearly Feasible Scenario. Other vehicles, such as those used in construction or mining are not included. Aggregate oil demand figures exclude biofuels consumption for road transportation. We consider that the combustion of a barrel of oil equivalent results in ~405 kg CO_2. We assume efficiency gains of 0.7% p.a. for ICE and 1.6% p.a. for BEV.

SOURCE: Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook;* MPP (2022), *Making Zero-Emissions Trucking Possible;* IEA (2023), *Emissions from Oil and Gas Operations in Net Zero Transitions.*

Exhibit 1.6

In the Accelerated but Clearly Feasible (ACF) Scenario, cumulative CO_2 emissions are still projected to reach approximately 128 $GtCO_2$, primarily due to the use of combustion engines

Total road transport energy demand and cumulative emissions in the ACF Scenario



NOTE: Other vehicles, such as those used in construction or mining are not included. Aggregate oil demand figures exclude biofuels consumption for road transportation. We consider that the combustion of a barrel of oil equivalent results in ~405 $kgCO_2$. We assume efficiency gains of 0.7% p.a. for ICE and 1.6% p.a. for BEV.

SOURCE: Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook;* MPP (2022), *Making Zero-Emissions Trucking Possible;* IEA (2023), *Emissions from Oil and Gas Operations in Net Zero Transitions.*

It is therefore important to assess whether, alongside supply-side decarbonisation via electrification, it is possible to further reduce cumulative emissions through energy productivity improvements, whether relating to the declining fleet of Internal Combustion Engines (ICE) vehicles, the increasing fleet of Electric Vehicles (EVs), or both.

This report assesses this potential in five chapters, considering:

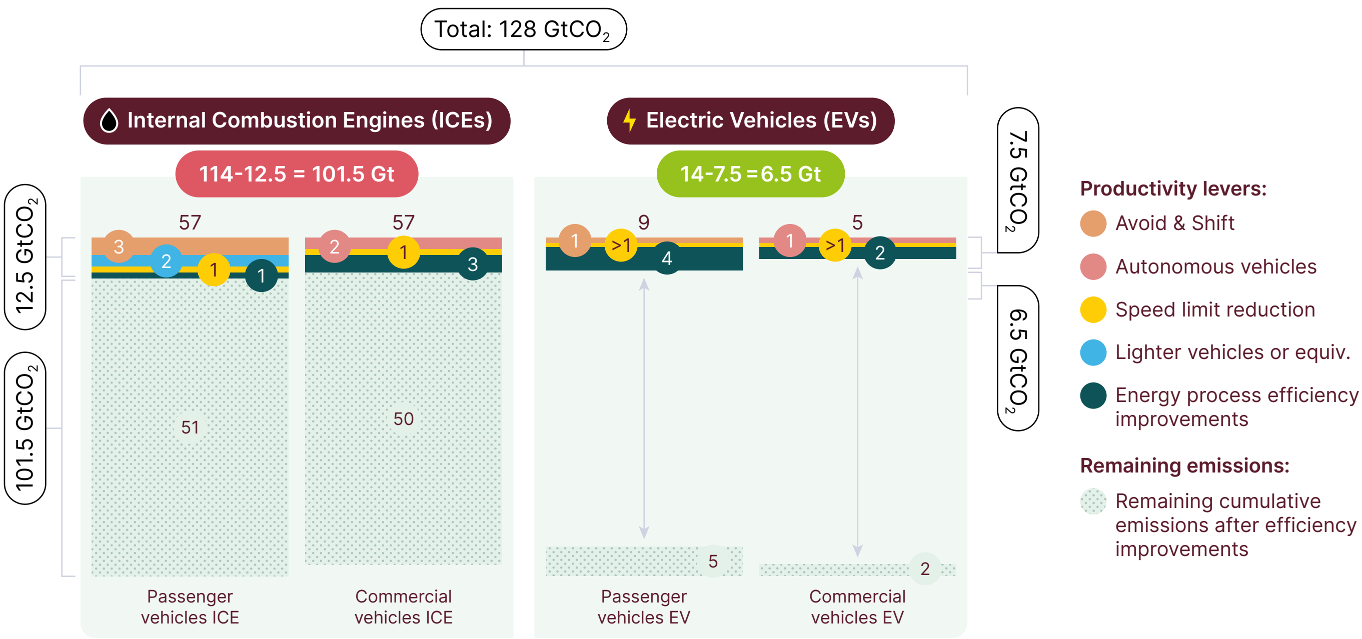
1. **The primary role of electrification**, which is both the key to supply-side decarbonisation and the most important driver of energy productivity improvement – both at the final energy level and at the primary energy level, provided power generation – including new generation - is itself decarbonised.
2. **Potential improvements in energy process efficiency**, achieved through improved energy efficiency of both ICE and EV vehicles, reductions in vehicle size, or changes in driving style.
3. **Potential improvements in service efficiency**, achieved via better urban design and modal shift, where the potential is significant but inherently difficult to assess.
4. **The impact of autonomous vehicles** on both energy process efficiency and service efficiency, which could be either positive or negative.
5. **Conclusions on aggregate potential and a summary of key policies to seize this potential.**

Exhibit 1.7 sets out the relative size of the energy productivity levers for both passenger and commercial vehicles. In total, if all are combined, approximately 20 $GtCO_2$ emissions could be avoided in the coming three decades thanks to these policies.

Exhibit 1.7

Total cumulative emissions of 128 Gt from ICEs and EVs can be reduced to 108 Gt

Projected remaining cumulative CO_2 emissions of passenger cars and commercial vehicles between 2023 and 2050 after productivity improvements
$GtCO_2$



NOTE: We consider that the combustion of a barrel of oil equivalent results ~405 $kgCO_2$. Productivity levers: 20% efficiency gains for ICEs by 2050, 50% efficiency gains for EVs by 2035, 20 km/h speed limit reduction on highways and 30 km/h speed limit in urban areas, ban of vehicles weighting more than 1.8 tonnes, 36% demand reduction by 2050 through avoid & shift levers, 20% AV efficiency gains for EV commercial vehicles and 5% for ICE vehicles. Differences in cumulative emissions attributed with LMDI (Logarithmic Mean Divisia Index) methodology.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

Electrification is efficiency: Leading energy productivity in road transport

2

Electrification will be the predominant driver of supply-side decarbonisation of road transport, replacing fossil fuel-powered vehicles with vehicles powered by zero-carbon electricity. Additionally, **electrification will itself also be the largest driver of energy productivity improvement in the road transport sector**, greatly exceeding the potential impact of the additional efficiency improvements considered in Chapters 2, 3 and 4. **At the final energy demand level, this reflects the inherent superior efficiency of electric vs. fossil fuel-based vehicles. At the primary energy demand level, decarbonisation of power systems is required to maximise these energy productivity gains.**

EVs are already cost-competitive to run and purchase in many markets compared to ICEs, and many manufacturers have targets to increase or only sell EVs as part of their fleet.[9] Uptake is accelerating: In 2025, EVs are expected to represent one-quarter of total passengers vehicles sales. In 2024, EVs represented 40% of China's passenger vehicle sales, and 10-25% of US' and EU's sales. In emerging markets sales shares almost doubled in 2024: from 2.5% to 4%. Since 2021, the global car fleet of EVs has tripled.[10] To support this growth, power systems must prepare for rising electricity demand by expanding charging infrastructure, promoting sustainable supply of critical minerals, and enhancing battery recycling efforts.[11]

2.1 Inherent efficiency advantage and impact on final energy demand

As Exhibit 2.1 illustrates, EVs are inherently more efficient than ICE vehicles, which waste about 75% of the input energy as heat, converting only 25% to kinetic energy. In contrast, typical EVs can convert about 67% of battery energy into kinetic energy. Additionally, EVs can recapture another 22% of energy through regenerative braking during deceleration, downhill movement and active braking.[12]

This also holds for commercial EVs – in a recent study, the International Council on Clean Transportation (The ICCT) highlighted that battery-electric heavy-duty vehicle (HDV) are on average 70% more efficient than diesel HDV.[13]

As a result, a fully electrified road transport system will be far more energy efficient at the final energy demand level, even with only modest future improvements in EV technical efficiency. Exhibit 2.2 shows what final energy demand would be in 2050, given ACF assumptions about the growth of vehicle numbers and kilometres travelled, if all vehicles were electric vs. if all were ICEs.

- In the ICE case, with an assumed energy efficiency improvement of 0.7% per annum, **2050 total final energy demand would be the equivalent of 19,200 TWh**.
- In the EV case, **this could be reduced by 71% to 5,600 TWh** (assuming constant EV technical efficiency improvements from now to 2050 at the same 0.7% per annum rate).
- In the EV case assuming further improvements in EV technical efficiency to 1.6% per annum (considered in Chapter 3) **would achieve an additional 1,100 TWh reduction to total final energy demand to 4,500 TWh**.

Electrification itself is therefore the most significant lever to improve energy productivity at the final energy demand level.

2.2 Impact on primary energy demand

At the primary energy demand level, we also need to account for energy losses incurred before the fuel or electricity is put into the vehicle [Exhibit 2.3].

- In the case of petrol or diesel, these losses arise in oil production and refining and would add 3,400 TWh to total "well-to-wheel" energy requirements in a 2050 100% ICE case, thus leading to the equivalent of a total 22,600 TWh of primary demand.

9 ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

10 IEA (2025), *Global EV Outlook.*

11 Sustainable Mobility for All (2022), *Electromobility and Renewable Electricity, Developing Infrastructure for Synergies*; ETC (2023), *Material and Resources Requirements for the Energy Transition.*

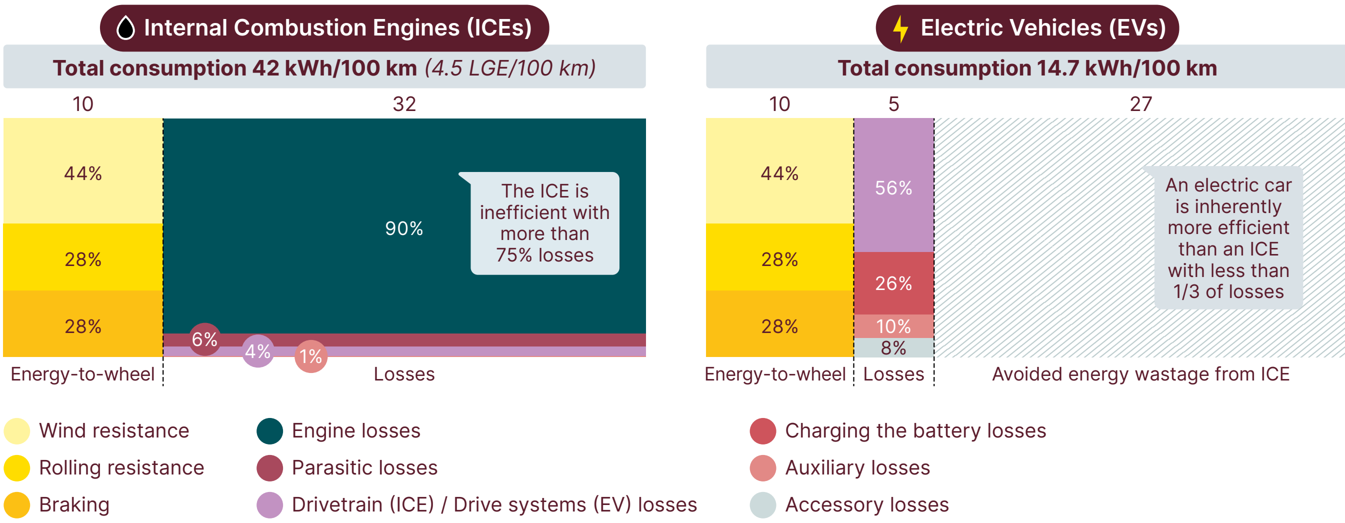
12 U.S. Department of Energy, *Where the Energy Goes: Electric Cars,* available at https://www.fueleconomy.gov/feg/atv-ev.shtml. [Accessed 04/10/24].

13 The ICCT (2023), *A total cost of ownership comparison of truck decarbonization pathways in Europe.*

Exhibit 2.1

Today, when comparing equivalent models, EVs are 3x as efficient as ICEs

Comparison of Hyundai Kona and electric Hyundai Kona 2024 energy efficiency
kWh/100 km and %



NOTE: We do not consider regenerative braking and potential energy reduction for EVs. We take a consumption of 14.7 kWh per 100 km for the Hyundai Kona Electric 2024 and 4.5 LGE (litre of gasoline equivalent) per 100 km for the Hyundai Kona 2024. There are 9.3 kWh per LGE. Energy use and losses vary from vehicle to vehicle. These estimates are provided to illustrate the general differences in energy flow in different vehicle types during different drive cycles.

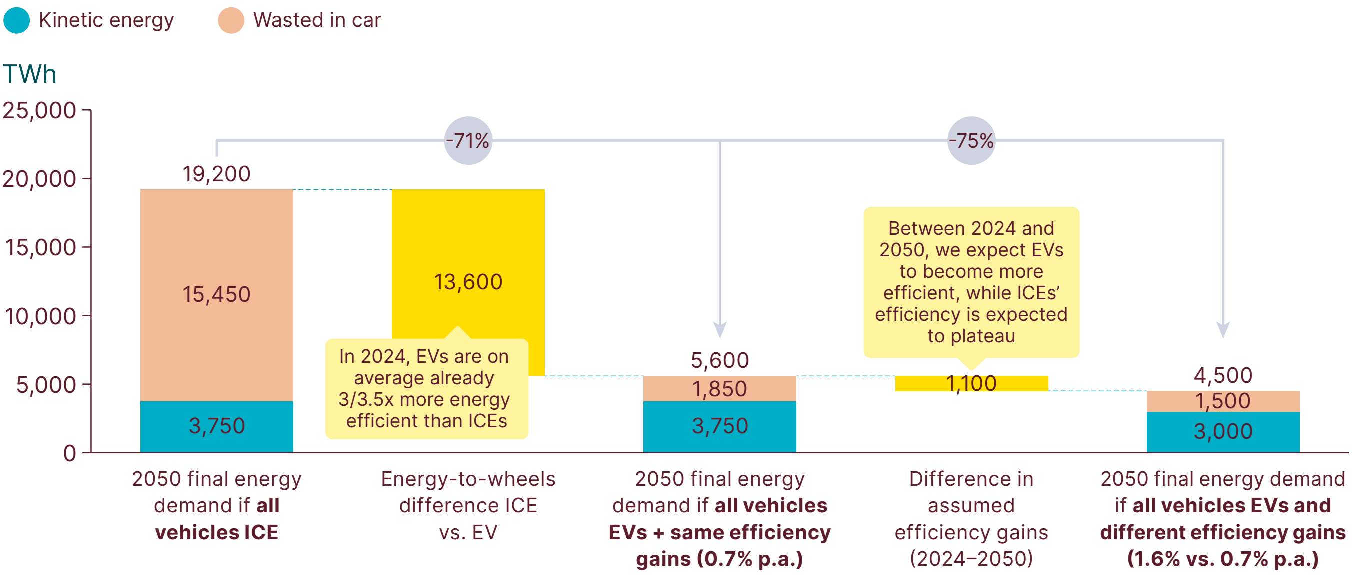
SOURCE: Systemiq analysis for the ETC; US Department of Energy, available at https://fueleconomy.gov/feg/atv.shtml. [Accessed 10/04/2024]; US Department of Energy, available at https://www.fueleconomy.gov/feg/atv-ev.shtml. [Accessed 10/04/2024]; GFEI (2023), *Trends in the global vehicle fleet 2023.*

Exhibit 2.2

Electrifying road transport would reduce final energy demand by 75% without any other energy productivity improvements

Passenger car final energy demand under a full ICE and a full EV scenario in 2050

ⓘ EVs are already on average more than three times as efficient as gasoline, and could become four times as efficient by 2050



NOTE: For final energy demand, demand for transport of ~30,500 billion km in 2050, with a fleet of 1.8 billion vehicles; In 2024, new EVs consume on average 20 kWh per 100 km, and new ICEs 7.4 LGE per 100 km. We consider efficiency improvements of 1.6% p.a. for EVs and 0.7% p.a. for ICEs, respectively reaching 12.9 kWh per 100 km and 6.1 LGE per 100 km in 2050. There are 9.3 kWh per LGE. 5% electricity efficiency losses are assumed as well.

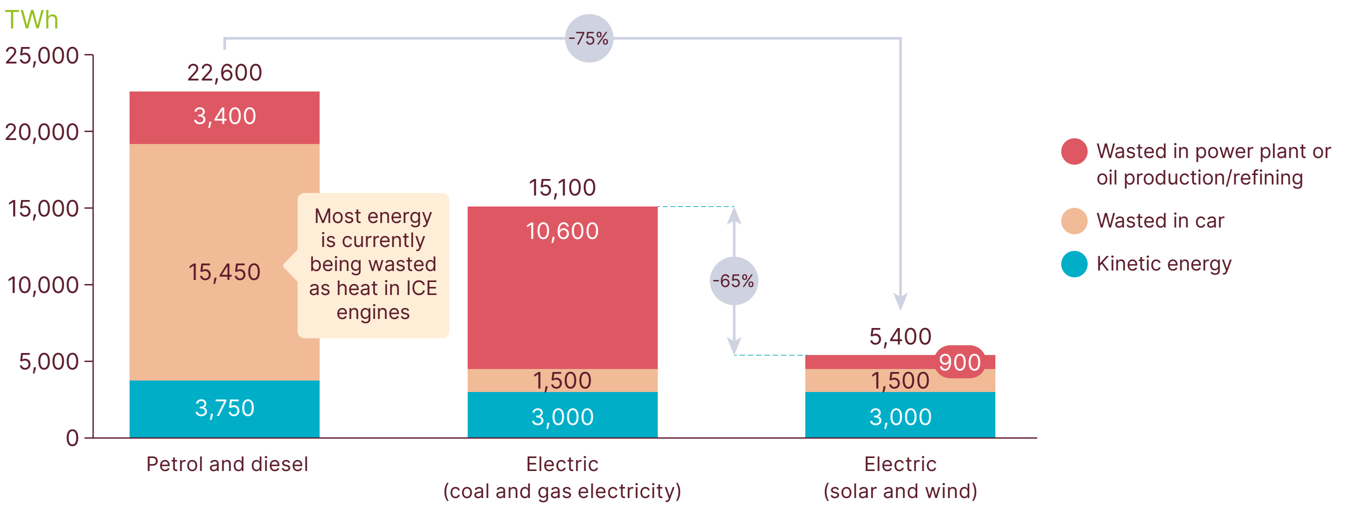
SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition.*

Exhibit 2.3

For maximum efficiency at primary energy level (and minimum emissions) EVs should be powered by low-carbon electricity

Primary energy demand in 2050 under various scenarios

ⓘ **EVs combined with low-carbon energy will reduce our overall primary energy demand by ~75%**



NOTE: For primary energy demand, energy efficiency of 85% from fossil fuel extraction to tanker, energy efficiency of 30% for fossil fuel power and 83% for renewables power (e.g., electricity conversion and transmission losses). Focus is only on passenger vehicles. We assume the average energy-to-wheel energy requirement in 2050 is 9 kWh per 100 km for a medium size car, excluding auxiliaries. We assume demand for transport of ~30,500 billion km in 2050. 5% electricity efficiency losses are assumed as well.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition*.

- In the EV case, losses arise in thermal power generation, with coal plants typically around 32–42% efficient and gas plants 34–60%.[14] If all the electricity used in the 100% EV case came from coal or gas plants, this could add 10,600 TWh losses to the 4,500 TWh of final energy demand in 2050, therefore leading to a 15,100 TWh primary energy requirement.

This exercise illustrates that even if power systems remain carbon-intensive, switching to EVs would overall reduce primary energy demand (and therefore emissions).[15] But it also highlights the importance of decarbonising power systems to bring primary energy demand (and corresponding emissions) down close to the final energy level. Total primary energy used could fall to as low as 5,400 TWh in an electricity system dominated by solar and wind.

14 A. Albatayneh et al. (2020), *Comparison of the Overall Energy Efficiency for Internal Combustion Engine Vehicles and Electric Vehicles*.

15 Carbon Brief (2023), *Factcheck: 21 misleading myths about electric vehicles*, available at https://www.carbonbrief.org/factcheck-21-misleading-myths-about-electric-vehicles/. [Accessed 04/10/2024]. Note: EVs in China already cut carbon emissions by 40% compared to ICEs in 2020, despite the grid being 61% coal-powered at the time (it has reduced coal usage since).

Exhibit 2.4 shows our ACF scenario assumptions about the pace at which the carbon intensity of electricity generated (gCO_2e per kWh) can be reduced globally and in major nations. Even in grids today, most EV use cases will save emissions compared to an ICE, given the emissions intensity of total electricity required compared with the emissions intensity of total fossil production required. Recent analyses have shown that EVs in China already cut carbon emissions by 40% compared to ICE cars in 2020, despite the grid being 61% coal-powered[16] at that date (the share of coal power has declined further since).[17]

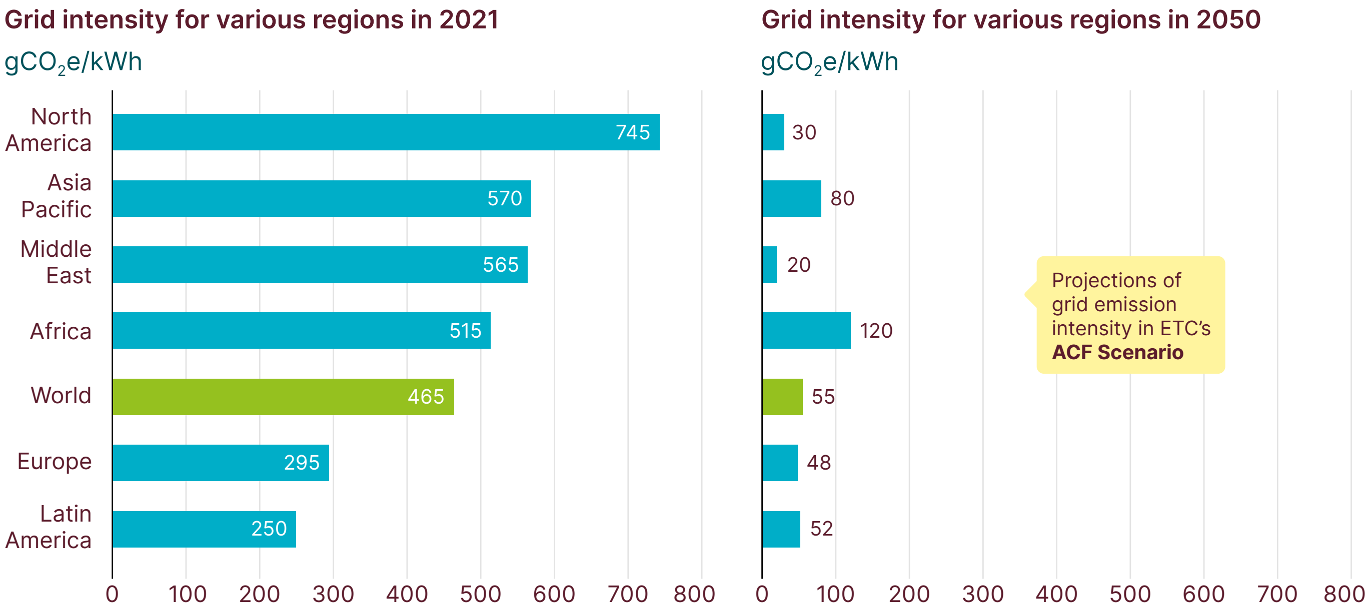
Achieving and ideally accelerating this pace of grid emissions intensity reduction is vital. A 10-year delay in the pace of global reduction (with 2050 global carbon intensity at 99 gCO_2e per kWh rather than 55 gCO_2e)[18] would have a much bigger impact (around 5.8 $GtCO_2$) on cumulative emissions than any of the energy process and service efficiency improvements considered in Chapters 3 and 4.[19]

Road transport should therefore be electrified wherever feasible, and direct electrification is certain to dominate passenger cars, two-and-three-wheelers and light/medium duty commercial vehicles. The open question is how large a role other solutions – particularly Hydrogen Fuel Cell Electric Vehicles (FCEVs) – will play in the heavy-duty long-distance truck segment[20]. The optimal solution will reflect the balance between:

- The potential range of advantages of FCEVs vs. Battery EVs, where FCEVs may be able to have greater stores of energy on board of commercial vehicles that drive longer distances.
- The overall energy efficiency of FCEVs, which is impacted by high energy demands and operational costs. Significant **heat losses** occur during the in-vehicle **conversion of hydrogen to electricity**, as well as throughout the **hydrogen production** process—including electrolysis, transportation, storage, and distribution—reducing FCEVs efficiency.[21]

Exhibit 2.4

Power sector emissions must drastically decrease to fully decarbonise mobility



NOTE: ACF = Accelerated but Clearly Feasible Scenario.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition.*

16 CarbonBrief (2023), *Factcheck: 21 misleading myths about electric vehicles,* available at https://www.carbonbrief.org/factcheck-21-misleading-myths-about-electric-vehicles/. [Accessed 04/10/2024].

17 CarbonBrief (2023), *Factcheck: 21 misleading myths about electric vehicles,* available at https://www.carbonbrief.org/factcheck-21-misleading-myths-about-electric-vehicles/. [Accessed 04/10/2024].

18 We assume the ACF grid intensity target is reached by 2060 instead of 2050. Consequently, the continuous annual decrease in grid intensity is 5.4% in this delayed scenario, compared to 7.2% in the original timeline.

19 Systemiq analysis for the ETC.

20 Energy efficiency differs by vehicle type/weight. The ICCT (2023), *A total cost of ownership comparison of truck decarbonization pathways in Europe.*

21 ETC (2021), *Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy.*

In fact, as illustrated in the exhibit below, EVs are significantly more efficient than FCEVs, and FCEVs are comparable to ICEs in energy efficiency terms. In final energy demand terms, EVs are 42–65% more efficient than FCEVs. In terms of primary energy demand, EVs are 52–77% more efficient than FCEVs. For HDVs, battery-electric trucks can be 50% more efficient today than FCEVs; by 2040 that difference should still be at 40%.[22] Battery electric truck sales are already soaring in China, capturing 22% market share in H1 2025, up from 9% in H1 2022, and forecast to capture at least 50% of the market by 2028.[23]

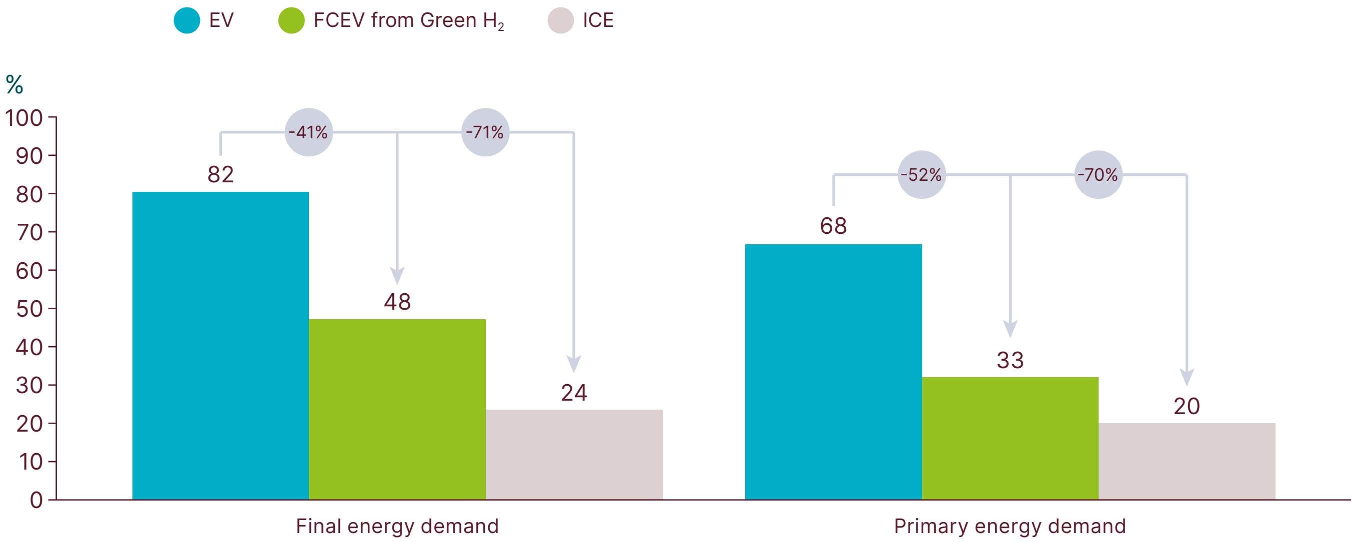
The next chapters explore energy efficiency improvements beyond electrification by examining [Exhibit 2.6]:

- **Energy process efficiency in Chapter 3,** such as technical improvements of ICEs and EVs, changes in vehicle attributes or efficient driving practices (e.g., eco-driving, reduced speed limit).
- **Service efficiency in Chapter 4,** such as avoid and shift levers.
- **Autonomous vehicles in Chapter 5,** a potentially transversal efficiency lever.

Exhibit 2.5

To maximise efficiency at both final and primary energy levels, EVs should be prioritised over FCEVs

Energy efficiency depending on drivetrain



NOTE: FCEV = Fuel Cell Electric Vehicle; H_2 = Hydrogen; Green hydrogen refers to hydrogen produced by electrolysis with renewables; Blue hydrogen refers to hydrogen produced through steam methane reforming (SMR) with carbon capture and storage (CCS) on top. For primary energy demand, we consider energy efficiency of 83% for renewables power (e.g., electricity conversion and transmission losses), 68% for green electrolysis, 55% for SMR with CCS and 85% from fossil fuel extraction to tanker.

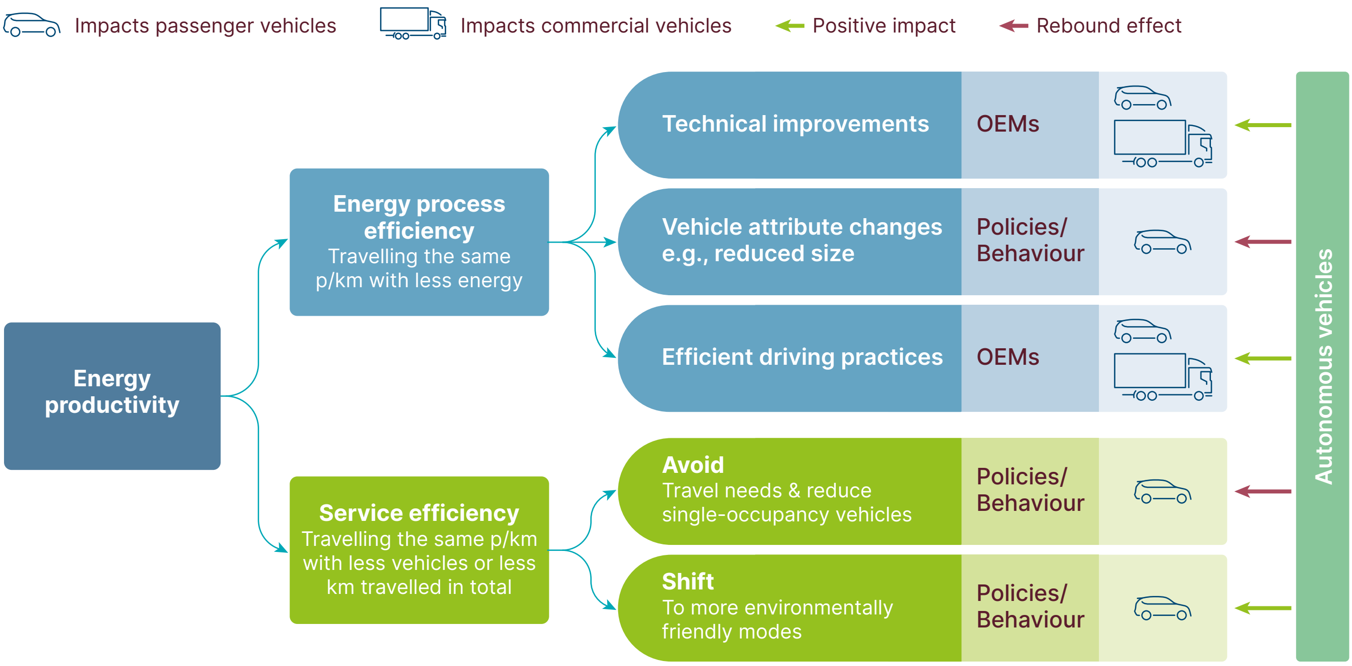
SOURCE: Systemiq analysis for the ETC; The Guardian (2024), *Will hydrogen overtake batteries in the race for zero-emission cars,* available at https://www.theguardian.com/business/2024/feb/13/will-hydrogen-overtake-batteries-in-the-race-for-zero-emissioncars#:~:text=He%20placed%20hydrogen%20for%20cars,Liebreich%2C%20without%20a%20moment's%20hesitation. [Accessed 20/02/2024].

22 The ICCT (2023), *A total cost of ownership comparison of truck decarbonization pathways in Europe.*

23 IEEFA (2025), *Surging electric truck sales stall China's LNG trucking boom.*

Exhibit 2.6

Additional potential for energy productivity in road transport, beyond electrification



NOTE: Energy productivity measures the amount of economic output that is produced per unit of gross available energy. OEM stands for original equipment manufacturer. P/km refers to passenger per kilometres.

SOURCE: Systemiq analysis for the ETC.

Energy process efficiency: Multiple actions can deliver significant potential

3

As discussed in the previous section, electrification will itself be the strongest driver of road transport energy efficiency improvements. Exhibit 2.6 summarises its impact on cumulative emissions between now and 2050:

- **With no electrification and no efficiency gains (e.g., from a fully ICE fleet), cumulative road sector emissions would reach 208 $GtCO_2$** (119 $GtCO_2$ for passenger cars and 89 $GtCO_2$ for commercial vehicles).[24]
- **With electrification and grid decarbonisation in line with the ACF scenario, those cumulative emissions are expected to fall by 80 $GtCO_2$ and reach around 128 $GtCO_2$**. These measures alone could therefore reduce emissions by ~40% (80 $GtCO_2$) from the upper bound (208 $GtCO_2$).

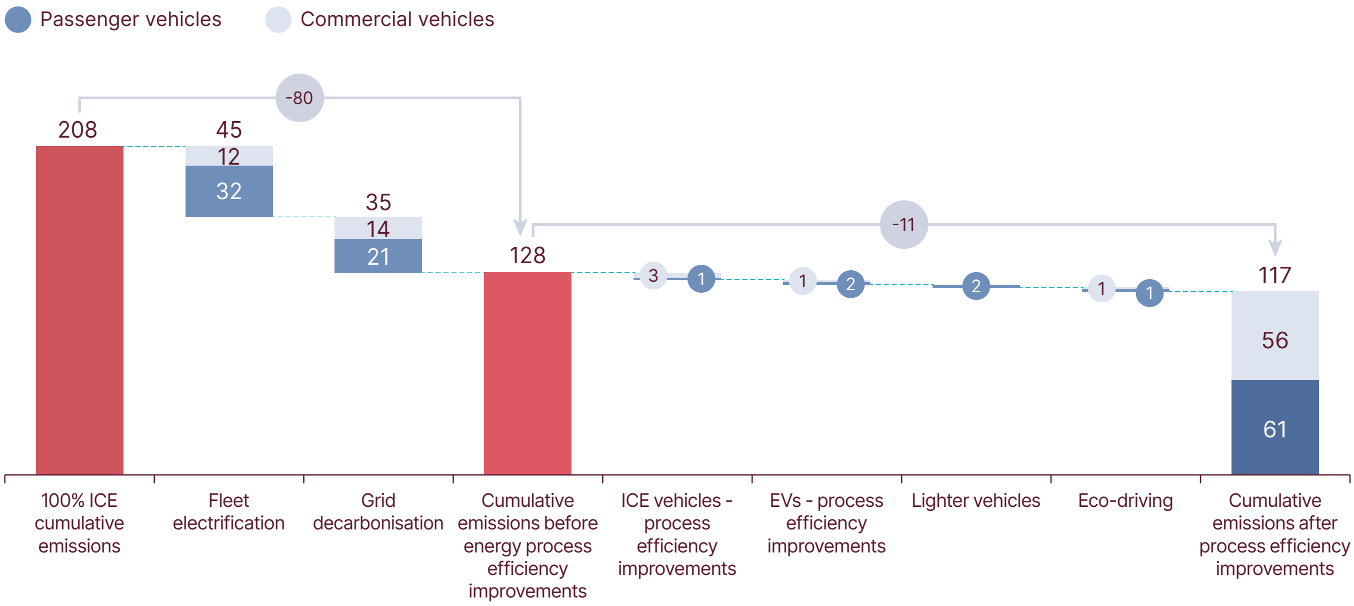
In this chapter, we explore the potential impact of energy process efficiency improvements (i.e. reductions in energy requirement per km travelled beyond those that will result automatically from electrification). This could further reduce cumulative emissions by 11 $GtCO_2$ to 117 $GtCO_2$ [Exhibit 3.1]. These reductions would result from:

1. Potential accelerated efficiency gains on new ICEs.
2. Potential efficiency gains on new EVs.
3. Potential efficiency gains related to vehicle attributes.
4. Potential efficiency gains associated with eco-driving practices.

Exhibit 3.1

Combining electrification and energy process efficiency, levers could reduce road sector emissions from 208 $GtCO_2$ to 117 $GtCO_2$

Projected cumulative CO_2 emissions between 2023 and 2050 in a full ICE scenario vs. with energy productivity levers
$GtCO_2$



NOTE: All ICEs means Internal Combustion Engine vehicles, EV means Electric Vehicles. We consider that the combustion of a barrel of oil equivalent results ~405 kg CO_2.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

24 Nearly exhausting the remaining total carbon budget of 250 $GtCO_2$ for a 1.5°C limit and 1,150 Gt for a 2°C limit as of January 2023. Forster et al. (2023), *Indicators of global climate change 2022: annual update of large-scale indicators of the state the climate system and human influence.*

We estimate the total potential of productivity levers in a "realistic scenario" at 11 $GtCO_2$ of cumulative emissions between now and 2050 due to:

- Fuel efficiency improvements in new ICEs could reduce passenger car emissions by 1 $GtCO_2$ and commercial vehicle emissions by 3 $GtCO_2$.
- Ambitious technical efficiency gains in EVs could achieve 3 $GtCO_2$ cumulative emissions reduction.
- Measures such as reducing speed limits and moving to lighter vehicles are less impactful, contributing all together less than 4 $GtCO_2$ to cumulative emissions reduction.

3.1 Energy process efficiency improvements in the ICE fleet

3.1.1 The stock turnover effect

Before assessing the potential for accelerated improvement in the technical efficiency of new ICE vehicles, it is important to note that one of the most important factors determining the pace of improvement in the average efficiency of the ICE fleet is the pace at which existing ICE vehicles are replaced.

Today, cars on the road typically last around 18 years; vehicles retiring from the global vehicle stock in 2024 were therefore typically new vehicles from 2006; and a retiring 2006 ICE consumes approximately 37% more fuel than a new 2024 ICE.

The most important driver of past improvements in vehicle energy efficiency has therefore been the gradual replacement of old vehicles with new more efficient ones. And this effect would continue to drive significant improvements in average ICE fleet efficiency over the next 18 years even if there were no further improvements in the efficiency of new ICEs coming onto the road.

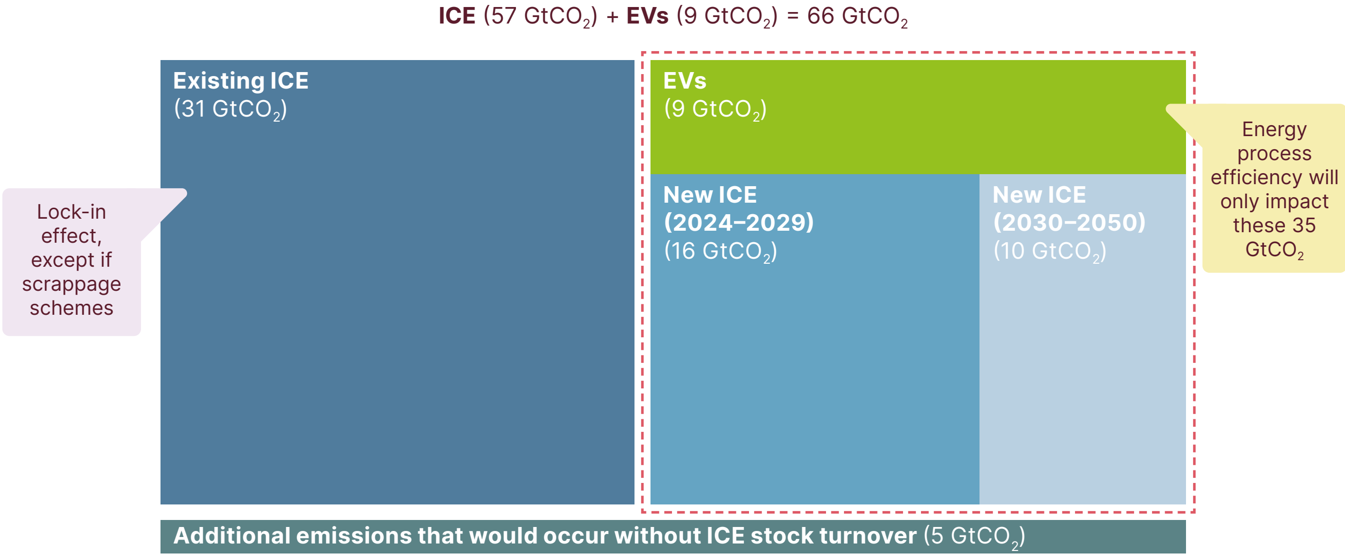
The scale of the potential impact for passenger cars can be illustrated in Exhibit 3.2. The figures show the cumulative emissions reductions between now and 2050 provided that electrification occurs in line with our ACF scenario, and the efficiency of new ICE vehicles has no further improvements.

- Emissions from existing passenger ICEs on the road today would amount to 31 $GtCO_2$ in the 18 years before all of these cars retire, while the emissions from new ICEs purchased from today onward could add a further 26 $GtCO_2$.

Exhibit 3.2

Passenger car emissions in Accelerated but Clearly Feasible (ACF) Scenario without new ICE efficiency improvements

Projected cumulative CO_2 emissions under the ACF Scenario without efficiency gains
2023–2050 $GtCO_2$



NOTE: ICE means Internal Combustion Engine Vehicles, EV means Electric Vehicles. We consider that the combustion of a barrel of oil equivalent results ~405 kg CO_2.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

- The combination of the 31 $GtCO_2$ and 26 $GtCO_2$ (57 $GtCO_2$) would however be 5 $GtCO_2$ higher if existing ICEs were not replaced with new ICEs[25] (even if there were no improvements in new ICE efficiency).
- And ICE passenger car emissions could be reduced below this 57 $GtCO_2$ figure if the stock turnover effect were faster than assumed in our base.[26]

We have not estimated the impact of the commercial vehicle stock turnover effect, but it is likely to be of a similar order of magnitude.

Our base case assumption for the fleet turnover effect is already reflected in the 128 Gt of cumulative emissions shown in Exhibit 3.1 after electrification but before other forms of energy productivity improvement.[27] But it is important that public policy is designed to ensure that the pace of fleet turnover is maintained and ideally accelerated, potentially delivering additional energy use and emission reductions:

- In developed and middle income countries where EV penetration will rise most rapidly, and where in some cases bans on new ICE sales beyond specific dates have been introduced or are being contemplated, there is a danger that some drivers may keep existing ICEs on the road for longer. Scrappage schemes and policies which eventually limit the use of existing ICEs will be required to avoid this effect. Scrappage schemes of the sort of China's settlement-car trade-in subsidy system, can conversely accelerate stock turnover, increasing the pace at which exiting vehicles are replaced either by EVs or by more efficient ICE vehicles.[28]
- Policies will be required to limit the extent to which old and inefficient ICEs from richer countries are not scrapped but sold to lower income countries and used for long times. This issue is already critical, as, for example, some African countries import vehicles with a median age of over 15 years, resulting in significantly higher local air pollution as well as carbon emissions.[29] International climate finance support for new EV financing and for scrappage policies should be considered alongside policies which limit second hand vehicle export and import accompanied by the development of charging infrastructure and grid expansion in lower income countries.

3.1.2 Potential improvements in new ICE passenger vehicles

From 2000 to 2020, passenger cars experienced a 1.7% annual improvement in energy consumed per km. This progress was driven by advancements in engine technology, the rise in EV adoption, and the introduction of hybrid powertrains.[30] In many countries, these improvements were driven by stringent fuel efficiency standards.[31]

Recent trends indicate that ICE fuel efficiency improvements have slowed. Many of the achievable gains in ICE engine efficiency have already been realised, and as OEMs shift their focus to EVs, there will be less research & development (R&D) on further ICE improvement.[32] In addition, as Section 2.2 discusses, increasing vehicle size and weight have offset underlying progress.

But further opportunities for efficiency improvement remain, including via increased electrification within ICE vehicles. Hybridisation, where electric batteries and motors are added alongside ICEs remains a crucial strategy for improving ICE vehicle efficiency. Mild and full-hybrid technologies offer a cost-effective way to reduce fuel consumption by providing electric assistance for enhanced efficiency.

Fuel economy standards can be an effective measure in the short run to help increase efficiency and reduce emissions. In the US, reinforcements to the Corporate Average Fuel Economy (CAFE) in 2022 increased fuel efficiency requirements by 8% for models 2024–25 and by 10% for model year 2026. This year China announced a 10% more stringent limit to fuel intensity in light commercial vehicles alongside reductions to passengers cars limits.[33] Chile's energy efficiency law from February 2021 also mandates fuel economy for new vehicles to comply to a 14.9 km per LGE 2020 baseline gradually increasing to 28.9 km per LGE in 2030. New Zealand's Clean Vehicle Standard from 2022 enacts a limit in emissions for passengers vehicles of 145 gCO_2 per km; with the standard increasing in stringency to 63.3 g CO_2 per km in 2027.[34] Other significant strategies for incentivising ICE efficiency include advanced combustion engines, lighter materials and better transmissions.

25 Stock turn-over is assessed over the replacement of an existing ICE for a new ICE, but it doesn't account for an existing ICE being replaced by a EV.

26 Technical efficiency in ICE might not be fully materialised because of differences between on-road usage and lab tests.

27 Cumulative emissions for the period between 2023 and 2050.

28 It should be noted that in some cases, scrapping vehicles too soon could itself be inefficiency from a lifecycle efficiency perspective. See Siyi Mi (2024), *China's Trade-In Policy May Unlock a $26 Billion EV Market*.

29 ITF (2023), *New but Used: The Electric Vehicle Transition and the Global Second-hand Car Trade.*

30 IEA (2022), *Energy Efficiency 2022.*

31 The ICCT, *Passenger vehicle greenhouse gas emissions and fuel consumption,* available at https://theicct.org/pv-fuel-economy/. List of economies: Australia, Brazil, Canada, Chile, China, EU, India, Japan, Mexico, New Zealand, South Korea, United Kingdom, United States.

32 For instance, Ford and Volkswagen are now allocating 73% and 68% of their R&D budgets, respectively, to EVs and digital technologies, signaling a reduced emphasis on further improving ICE efficiency. See IEA (2024), *Global EV Outlook 2023.*

33 IEA (2025), *Energy Efficiency.*

34 IEA (2022), *Energy Efficiency 2022.*

Taking into account external assessments of ICE passenger vehicle fuel efficiency potential, the ETC outlines a scenario aligned with ACF's initial productivity assumptions: a 0.7% annual efficiency improvement, leading to a total efficiency improvement of 20% by 2050.[35] This is broadly in line with BloombergNEF's (BNEF) forecasts of a 0.8% annual improvement from 2023 to 2040, leading to a total improvement of around 15% by 2040. This would lead to cumulative savings of 0.9 GtCO_2 for passenger vehicles.[36]

There could be the potential for further gains in a more ambitious scenario. By 2050, combining strategies such as reducing tyre rolling resistance, using lightweight materials and adopting mild and full hybrid drivetrains, **could deliver a theoretical 50% efficiency gain** [Exhibit 3.3].[37] This scenario is in line with an ambitious view expressed by the ICCT, where potential improvements ranging from 24–42% by 2035 could be achieved through the use of mild and full hybrid drivetrains, advanced combustion engines, lighter materials and better transmissions.[38]

Exhibit 3.3

By 2050, ICE vehicles can boost efficiency by 50% with hybrid drivetrains, low-rolling-resistance tyres, lightweight technologies and reduced drag

Lightweight materials
LIGHTWEIGHT TECHNOLOGIES

Selective use of lightweight materials to replace heavy steel.

Realistic Potential	Marginal
Ambitious Potential	-10%

Tyre rolling resistance
TYRE ROLLING RESISTANCE

Reducing tyre rolling resistance through use of specially designed tyres (e.g., Bridgestone) can also be applied to ICE.

Realistic Potential	-5%
Ambitious Potential	-18%

Strong hybridisation
HYBRID VEHICLES

Hybrid powertrains recover a portion of braking losses and improve overall driveline efficiency.

Realistic Potential	-15%
Ambitious Potential	-25%

Glider weight
LIGHTWEIGHT TECHNOLOGIES

Reduce glider weight by more than 20%.

Realistic Potential	Marginal
Ambitious Potential	-5%

Aerodynamic drag
OTHER IMPROVEMENTS

Reduce aerodynamic drag coefficient from 0.28 to 0.17 through closer attention to styling, wheel wells and vehicle rear geometry.

Realistic Potential	Marginal
Ambitious Potential	-4%

TOTAL IMPROVEMENT:

Combined effect of improvements

The maximum potential improvement for ICV is around 50%.

Realistic Potential	-20%
Ambitious Potential	-50%

However, looking ahead, fuel efficiency innovation will likely slow as most improvements are achieved and OEMs shift R&D from ICE models to EVs

NOTE: WLTP: Worldwide harmonised light vehicles test procedures. A glider is a fixed-wing aircraft that is supported in flight by the dynamic reaction of the air against its lifting surfaces, and whose free flight does not depend on an engine.

SOURCE: Bridgestone (2022), *Bridgestone develops hyper-efficient tyre for the Mercedez-Benz vision EQXX*; EPRI (2024), *Valuing Improvements in Electric Vehicle Efficiency;* The ICCT (2023), *Vision 2050 Strategies to align global transport well below 2° C.*

35 BNEF (2024), *The Lifecycle Emissions of Electric Vehicles;* ETC (2023), *Fossil Fuels in Transition: Committing to the Phase-down of All Fossil Fuels.*

36 Systemiq analysis for the ETC.

37 This would reduce new ICE passenger vehicle consumption from 7.4 LGE per 100 km in 2024 to 3.7 LGE per 100 km

38 The ICCT (2023), *Vision 2050 – Strategies to align global road transport with well below 2°C.*

To deliver these savings, enforcing mild or full hybridisation - effectively making ICEs more like EVs - will be the most effective strategy for reducing emissions in ICEs, given that around 650 million ICEs are still expected to enter the market by 2035. However, as detailed in Box C below, this strategy should not overshadow the transition to EVs or encourage OEMs to prioritise Plug-in Hybrid Electric Vehicles (PHEVs) over EVs. Governments should avoid over-subsidising hybrids, as PHEVs only achieve a 20% reduction in emissions, compared to the 75% reduction achieved by EVs.[39]

Box C

Distinguishing mild hybrid ICE with Plug-in Hybrid Electric Vehicles (PHEV).

ICEs can be improved through mild hybrid powertrains, which add a small electric motor to assist during acceleration and low speeds, thereby enhancing fuel efficiency. These vehicles primarily remain ICEs but offer a practical and cost-effective solution to reduce fuel consumption without needing external charging, making them simpler and more affordable than full hybrid vehicles. There is no charging which occurs via a plug.

In contrast, PHEVs have a plug for charging, similar to a full EV. They can run on 100% electric mode, though they also have an internal combustion engine. They are therefore often considered a bridge technology. However, their real-world efficiency often falls short as many drivers do not use the electric mode enough, relying mainly on the ICE mode and fossil fuels.

In the race against EVs, PHEVs are now in a weaker position compared to a few years ago due to policies favouring pure electric cars, rapid improvements in battery technology and widespread charging infrastructure. EVs are set to become the cheapest vehicles to purchase soon, while PHEVs face higher running costs and greater complexity due to their dual powertrains.[40]

3.1.3 Potential improvements in new ICE commercial vehicles

From 2000 to 2020, while the energy efficiency of light commercial vehicles improved annually by 1.7% per annum, that of HDVs only improved by 0.3% per annum on average according to the IEA.[41] Meanwhile, other studies indicate that the average fuel efficiency of EU tractor-trailers has remained stagnant for over a decade.[42,43]

These figures indicate that while there have been some advancements, significant potential for improvement remains in the commercial vehicle sector. Overall, major economies have made a significant regulatory push to reduce emissions and improve fuel efficiency of trucking, such as the EU's CO_2 emissions standards for HDVs and the Environment Protection Agency (EPA) standards in the US, both of which have seen recent proposals be strengthened.[44]

To meet these regulations, OEMs and fleet managers have tested several strategies to improve energy efficiency, including through advancements in aerodynamics, lightweighting, tyre rolling resistance, mild hybridisation and engine technology. However, while research programmes have demonstrated the potential for substantial efficiency gains, real-world implementation presents some challenges, around both additional costs as well as deployment in a fragmented industry. Consequently, commercial vehicle experts predict that only 15% to 20% efficiency gains would be achievable by 2030–2035.

The ETC has therefore outlined a scenario, aligned with ACF's initial productivity assumptions and experts interviews, which anticipates a 0.8% annual efficiency improvement, achieving 19% efficiency improvements by 2050. This would lead to cumulative emission savings of around 3 $GtCO_2$ for commercial vehicles.[45]

Similarly as with passenger vehicles, there could be the potential for further gains in a more ambitious scenario. By 2050, a full adoption of all strategies such as improving tractor and trailer aerodynamics, improving engines, reducing tyre rolling resistance, adopting mild and full hybrid drivetrains could achieve a theoretical 50% efficiency gain [Exhibit 3.4].

39 The ICCT (2024), *The risks of betting on biofuels with flex-fuel plug-in hybrid cars in Brazil.*

40 BNEF (2024), *Electric Vehicle Outlook.*

41 IEA (2022), *Energy Efficiency 2022.*

42 The ICCT (2021), *CO_2 emissions and fuel consumption standards for heavy-duty vehicles in the European Union.*

43 A tractor-trailer is a large truck in two parts, one in the front for the driver and one behind where goods are carried. The connection between the two parts can bend in order to help the vehicle turn corners.

44 The ICCT (2024), *The revised CO_2 standards for heavy-duty vehicles in the European Union;* EPA (2024), *Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses.*

45 Cumulative emissions for the period between 2023 and 2050.

Exhibit 3.4

By 2030, ICE long-haul commercial vehicles can realistically boost efficiency by 20%

Engine improvements
ENGINE TECHNOLOGIES

Examples include engine friction reduction, combustion optimisation, turbo improvements, engine downsizing and waste heat recovery. Incremental engine technology levels can further improve efficiency.

Realistic Potential	-5%
Ambitious Potential	-10%

Aerodynamics
ROAD LOAD REDUCTION

Improving tractor and trailer aerodynamics, such as using aerodynamic features and advanced designs.

Realistic Potential	-7%[D]
Ambitious Potential	-15%

Transmission
DRIVELINE

Improved transmission systems, including automated manual transmissions (AMTs), which have higher efficiency and optimise gear shifting.

Realistic Potential	Marginal
Ambitious Potential	-1%

Hybrid powertrain
DRIVELINE

Hybrid powertrains recover a portion of braking losses and improve overall driveline efficiency.

Realistic Potential	-7%[C]
Ambitious Potential	-10%

Tyre rolling resistance
TYRE ROLLING RESISTANCE

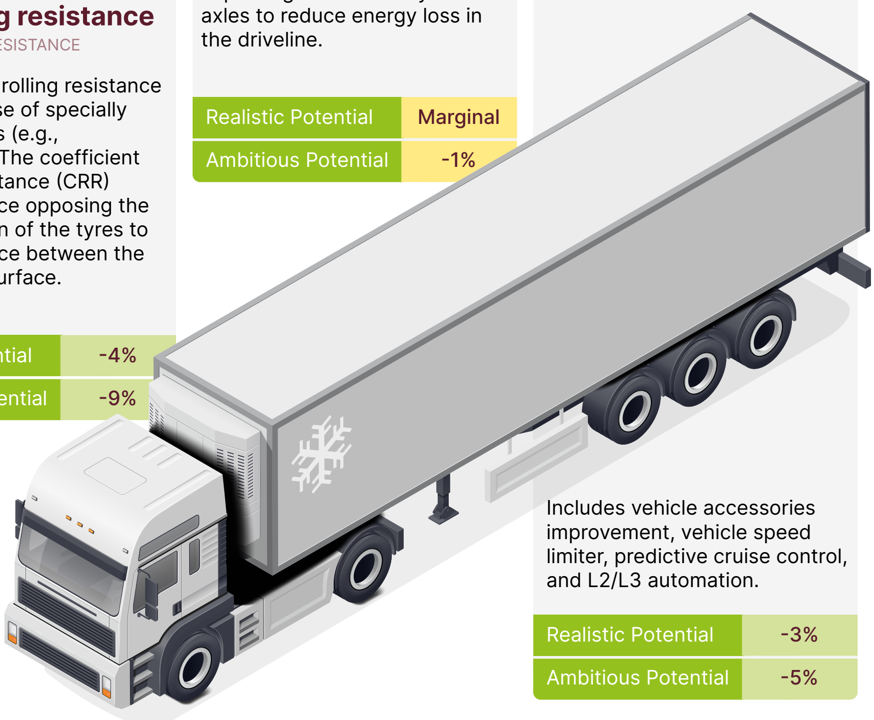
Reducing tyre rolling resistance through the use of specially designed tyres (e.g., Bridgestone). The coefficient of rolling resistance (CRR) relates the force opposing the rotating motion of the tyres to the normal force between the tyre and the surface.

Realistic Potential	-4%
Ambitious Potential	-9%

Axle efficiency
DRIVELINE

Improving the efficiency of the axles to reduce energy loss in the driveline.

Realistic Potential	Marginal
Ambitious Potential	-1%



Other improvements
VEHICLE

Includes vehicle accessories improvement, vehicle speed limiter, predictive cruise control, and L2/L3 automation.

Realistic Potential	-3%
Ambitious Potential	-5%

Lightweighting
ROAD LOAD REDUCTION

Utilising lightweight materials and design to reduce vehicle curb weight. This allows for increased payload without changing fuel consumption or reduces fuel consumption for volume-constrained vehicles.

Realistic Potential	Marginal
Ambitious Potential	-1.5%

TOTAL IMPROVEMENT:

Combined effect of improvements

Combined effect of the aforementioned improvements leads to significant overall efficiency gains.

Realistic Potential	-20%[D]
Ambitious Potential	-50%

NOTE: (C) But not cost-effective; (D)Trailer excluded; A tractor is the vehicle with the engine and driver's cab used to pull a trailer, which is the unpowered unit designed to carry cargo.

SOURCE: Systemiq analysis for the ETC; The ICCT (2017), *Fuel efficiency technology in European heavy-duty vehicles: Baseline and potential for the 2020–2030 timeframe.*

3.2 Potential technical efficiency gains in EVs

EVs are already inherently more energy efficient than ICE vehicles, but there is also significant potential for further efficiency gains. Key technologies for improving vehicle energy efficiency include reducing weight without compromising size or safety, reducing aerodynamic drag, improving battery and powertrain efficiency, and increasing battery energy density.

Significant advancements can be achieved in new battery development and the adoption of new in-wheel motors.

The ETC estimates that a combination of these efficiency improvements [Exhibit 3.5] could reduce the energy required for passenger EVs by 50% by 2050. Similar improvements can be expected in commercial vehicles which can benefit from these same technologies.

This could reduce average passenger EV electricity consumption from 20 kWh per 100 km today to 10 kWh per 100 km by 2035, lowering required annual electricity demand by 3,200 TWh by 2050.[46] If accomplished without raising vehicle costs, EV efficiency gains could also deliver to consumers energy cost savings of billions of dollars annually. Indeed, since increased efficiency will reduce required battery size for any given range, it could drive reductions in upfront vehicle cost as well as operating cost.[47]

In terms of emissions, **this could result in cumulative savings of 3 $GtCO_2$, of which around 1.5 $GtCO_2$ for passenger vehicles and more than 1 $GtCO_2$ for commercial vehicles.**[48]

Exhibit 3.5

Electric vehicle efficiency could double between 2024 and 2050

Higher density batteries

REDUCE VEHICLE WEIGHT

Energy density of lithium-ion batteries will increase by a further 60–80% by around 2035. Solid-state battery is also expected to be the technology of the 2030s.

Lightweight materials

REDUCE VEHICLE WEIGHT

Selective use of lightweight materials to replace heavy steel.

Estimated efficiency potential -20%

Reducing front area

OTHER IMPROVEMENTS

Smarter packaging, reducing width by setting front as well as rear wheels completely flush with the sides.

Estimated efficiency potential -6%

In-wheel motors

DRIVE UNIT IMPROVEMENTS

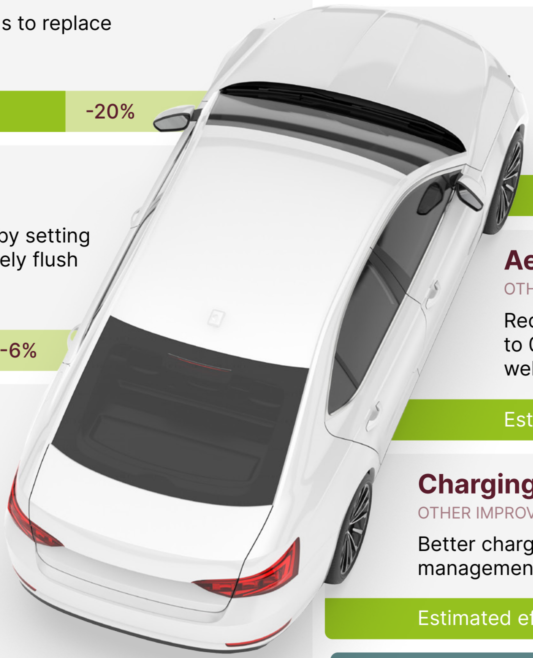
In-wheel motors integrate the electric motor into the wheel hub, enhancing overall efficiency by up to 20% and requiring less space by eliminating the need for a conventional drivetrain.

Other improvements

DRIVE UNIT IMPROVEMENTS

Reducing iron losses, better wires, etc.

Estimated efficiency potential -20%



Auxiliary improvements

AUXILIARIES (EXCLUDED IN WLTP)

More efficient accessories: AC, seat heating, optimal in-car energy consumption. Auxiliaries can currently increase electric consumption by up to 50%.

Estimated efficiency potential -15 – 25%

Tyre rolling resistance

TYRE ROLLING RESISTANCE

Reducing tyre rolling resistance through use of specially designed tyres (e.g., Bridgestone).

Estimated efficiency potential -18%

Aerodynamic drag

OTHER IMPROVEMENTS

Reduce aerodynamic drag coefficient from 0.28 to 0.17 through closer attention to styling, wheel wells, and vehicle rear geometry.

Estimated efficiency potential -8%

Charging improvements

OTHER IMPROVEMENTS

Better charging cables, thicker cables, better thermal management systems in car.

Estimated efficiency potential -5%

TOTAL POTENTIAL IMPROVEMENT:

Combined effect of improvements

The combined effect of these modeled improvements for a 2050 high-efficiency car is a doubling of efficiency, from around 20 kWh/100 km to 10 kWh/100 km.

Estimated efficiency potential -50%

NOTE: WLTP: Worldwide harmonised light vehicles test procedures. There is a growing divergence between real-world and WLTP CO_2 emissions data for internal combustion engine cars and hybrid cars. On-board fuel and energy consumption monitoring (OBFCM) devices should be used, especially for EVs.

SOURCE: Deepdrive, available at https://www.deepdrive.tech/; Bridgestone (2022), *Bridgestone develops hyper-efficient tyre for the Mercedez-Benz vision EQXX;* Fraunhofer (2023), *Alternative Battery Technologies Roadmap 2030+;* EPRI (2024), *Valuing Improvements in Electric Vehicle Efficiency;* The ICCT (2023), *Real-world performance of battery electric passenger cars in China.*

46 From 6,500 TWh for passenger vehicles in a 0% efficiency scenario in 2050 to 3,300 TWh in an aggressive scenario achieving 50% efficiency gains. Note: Manufacturer-reported values from lab tests often significantly differ from real-world consumption data. Real-world tests indicate that EVs use 29% to 44% more energy than lab figures, with current EVs averaging 16 kWh per 100 km in lab tests but higher in actual use. Accordingly, the ETC assumes that new EVs sold in 2024 will consume 20 kWh per 100 km on average, which is 25% higher than lab-tested values. See ICCT (2024), *The bigger the better? How battery size affects real-world energy consumption, cost of ownership, and life-cycle emissions of electric vehicles.*

47 Deepdrive's in-wheel motor could increase EV efficiency by 20%, thereby either reducing the battery weight by 20% or increasing the driving range by 20%. Choosing the first option could significantly reduce the total cost of a car, as batteries are the most significant cost driver of a battery-electric vehicle (BEV). See Deepdrive, available at https://www.deepdrive.tech/ and BCG *(2023), The High-Stakes Race to Build Affordable B-Segment EVs in Europe.*

48 Cumulative emission being considered over the period between 2023 and 2050.

While many improvements in EV efficiency will occur naturally, public policies and focused OEM initiatives and targets are also vital.[49]

- Progress in China has been driven by policies setting industry development targets, incorporating vehicle performance criteria into purchase subsidy requirements, and adopting an NEV (New Energy Vehicle)[50] credit management scheme that rewards superior technical performance.[51] From 2012 to 2021, China's EV fleet-average nominal efficiency range doubled, with fleet average electricity consumption reaching 12.1 kWh per 100 km, making the governmental 2025 target of 12.0 kWh per 100 km seem conservative.[52]
- **OEMs are also playing a crucial role in advancing new EV technologies**. For instance, Bridgestone and Mercedes are developing tyres that reduce rolling resistance and weight by up to 20%.[53]

3.3 Efficiency improvements from weight reduction

Improvements in the technical energy efficiency of ICEs, and the energy efficiency benefits of electrification, have been significantly offset in recent years by increased vehicle weight. The average weight of new vehicles sold has increased by 30% from 1990 to 2019, from 950 kg to over 1200 kg.[54]

Analysis by the Global Fuel Economy Initiative (GFEI) suggests that in the absence of a trend towards heavier vehicles and in particular SUVs, energy use per km for ICEVs could have decreased at an average annual rate 30% greater than it did from 2010 to 2022.[55]

Energy consumption increases as vehicle weight increases but this effect is much more pronounced for ICEs than for EVs. This reflects the fact that while in both cases more energy is required to accelerate a heavier vehicle, EVs can recover in deceleration and braking a significant proportion of the energy used [Exhibit 3.6]. Nevertheless, fast charging infrastructure could also help the proliferation of smaller batteries, by reducing range requirements and therefore weight.

As a result, while policies which limit the size and weight of EVs are potentially very attractive for several reasons – e.g., to reduce traffic congestion or particulate emissions from tyre wear and tear – they would have only a limited impact on total electricity use and cumulative emissions. But limits on the size and weight of ICEs could have a significant effect. **In total we estimate that if all sales of new ICE vehicles weighing more than 1.8 tonnes were prohibited (or if consumer preferences changed), it could reduce total cumulative emissions by 1.6 GtCO_2.**[56,57]

A number of countries have introduced policies which aim to reduce vehicle weight.

- **Norway**: Norway has levied a purchase tax on ICE vehicles based on weight, CO_2, and NOx emissions since 1995. The weight tax applies to cars above 500 kg and increases linearly, with higher rates for cars above 1,200 kg and 1,500 kg.[58]
- **India**: Applies lower tax rates for EVs and FCEVs and differentiates tax rates between cars and SUVs, penalising the latter.[59]
- **Japan**: Taxation favoured smaller cars for a long time, with "kei-cars" benefitting from tax exemptions, contributing to their high market share. Kei-cars are also exempt from the requirement to own a dedicated parking spot.[60]
- **France**: Revised its "feebate" scheme in 2022 to levy additional taxes on heavier vehicles. Vehicles over 1,800 kg are subject to an extra €10 per kg tax, capped at €50,000. EVs, FCEVs, and PHEVs with an all-electric range over 50 km are exempt.[61]

49 The target year 2035 is selected to achieve the most efficiency gains in the next decade and to maximise the impact of these improvements on cumulative emissions and TWh, as the grid is projected to decarbonise linearly until 2050 in our ACF scenario.

50 In China, "new energy vehicle" is an umbrella term that encompasses battery electric, plug-in hybrid electric and hydrogen FCEVs. China formally kicked off its vehicle electrification journey over a decade ago when it released its first new energy vehicle (NEV) development plan in 2012. China State Council (2012), *Energy-saving and New Energy Vehicle Development Plan (2012-2020).*

51 The ICCT (2023), *Nine trends in the development of China's electric passenger car market.*

52 Ibid.

53 Electrive (2024), *China to pour millions into solid-state battery research.*

54 Together for 1.5, Accelerate Climate Action in Europe, *Increasing weight of passenger vehicles*, available at https://1point5.caneurope.org/france-weight-passenger-vehicles/. [Accessed 10/15/2024].

55 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

56 GFEI (2023), *Trends in the Global Vehicle Fleet 2023 – Managing the SUV Shift and the EV Transition*. Note: It is estimated that large SUVs consume an average of 10.5 LGE per 100 km and account for approximately 11% of new vehicle sales. Prohibiting these vehicles could reduce the average fuel consumption of new ICE vehicles sold by around 3% annually.

57 Cumulative emissions for the period between 2023 and 2050.

58 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

59 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

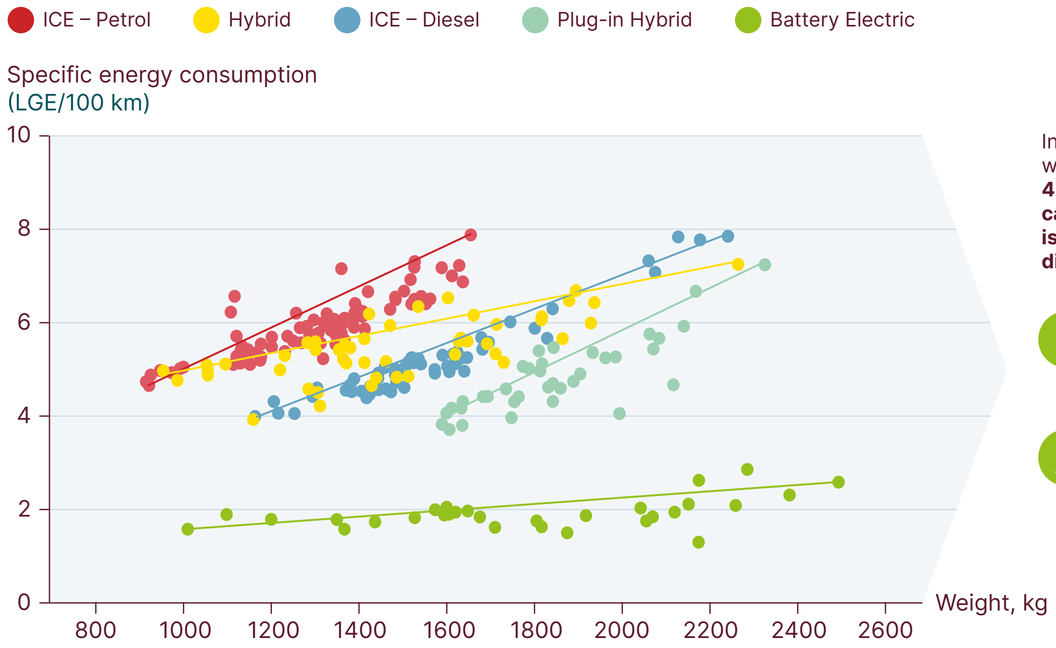
60 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

61 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

Exhibit 3.6

The heavier the car, the more it consumes, especially for ICEs that are inherently less efficient and lack the energy recovery capabilities of EVs

Specific energy consumption plotted against vehicle mass, by powertrain for top selling light-duty vehicles in Europe
LGE/100 km



In the US, a standard **ICE-SUV** weighs 800 kg more and **uses 45% more fuel than a medium car,** while for **EVs, the increase is 33% for the same weight difference.** Reasons are:

1. **EVs are inherently more efficient,** bigger vehicles therefore lose less energy.
2. **Regenerative braking benefits larger EVs,** offsetting some energy losses in heavier EVs compared to heavier ICEs.

NOTE: ICE-SUV means internal combustion SUV. Specific energy consumption for PHEV was calculated using a utility factor derived from the all-electric range reported in the EEA database using a function reflective of real-world usage. LGE means litre gasoline equivalent.

SOURCE: Systemiq analysis for the ETC; Fraunhofer ISI (2021), *Specific energy consumption of electricity for driving phased in all-electric mode and specific fuel consumption for other driving phases;* Global Fuel Economy Initiative (2023), *Trends in the global vehicle fleet 2023;* IEA (2023), *Energy Efficiency 2023.*

- **Paris**: Recently tripled parking fees in the city centre, reaching €18 per hour for hybrid or combustion engine vehicles weighing over 1.6 metric tonnes and electric SUVs weighing over 2 metric tonnes. [62,63]

The total impact of these policies on eventual total electricity consumption will be limited, but they could usefully reduce short-term oil consumption and are highly desirable because of other environmental objectives.

3.4 Efficiency gains from improvements in driving style and speed limit reductions

Efficient driving practices can also further reduce the amount of energy used per km drive.

- **Drivers** can practice so called "eco-driving" by driving more slowly and more smoothly, avoiding sudden acceleration, optimising gear shifts, reducing idling and using auxiliaries wisely, such as preferring seat heating over cabin heating and using smart climate control systems.
- **Governments** can require lower speed driving via tighter speed limits [Box D].[64]

It is inherently difficult to quantify the impact of the full range of "eco driving" actions, but estimates can be made of the impact of tighter speed limits.

There is a clear correlation between driving speeds and energy efficiency, with vehicle fuel consumption varying significantly with speed [see Exhibit 3.7].

62 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

63 GFEI (2023), *Trends in the global vehicle fleet 2023 – managing the SUV shift and the EV transition.*

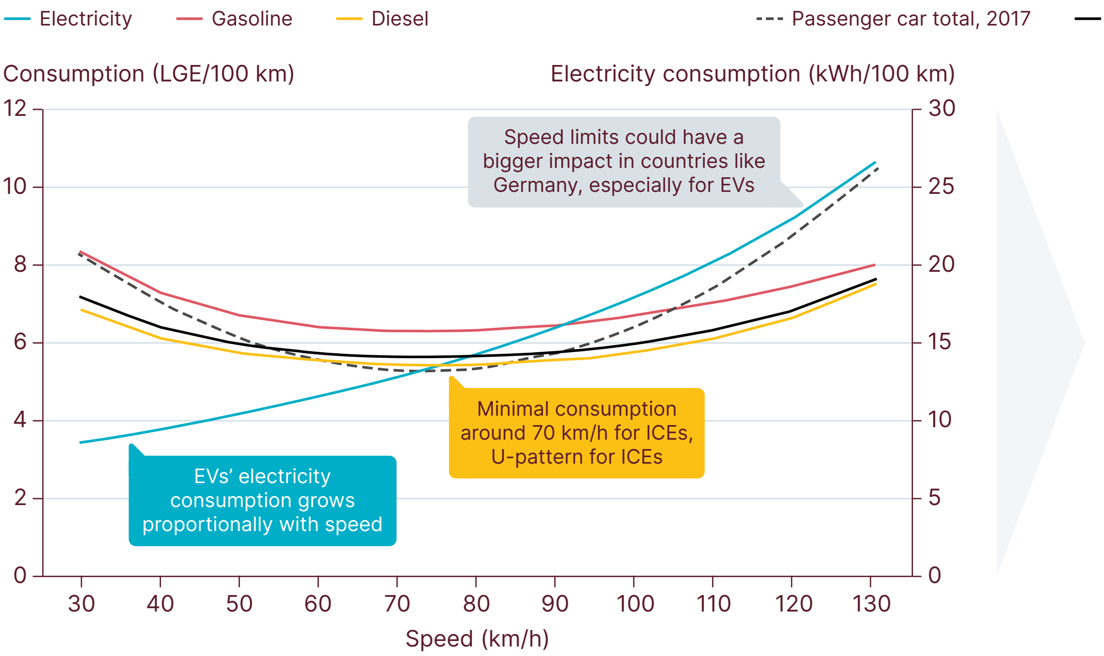
64 Although recognising that this would require overcoming some public acceptance barriers, such as in Germany. See CleanEnergyWire (2024), *Autobahn speed limit debate flares up again as Germany enters election campaign,* available at https://www.cleanenergywire.org/news/autobahn-speed-limit-debate-flares-again-germany-enters-election-campaign.

- **For ICE cars, this relationship is represented by a U-shaped consumption curve, with optimal efficiency around 70 km per hour.** Studies show that lowering speed limits on high-speed roads reduces both fuel consumption and emissions, especially when speeds deviate from this optimal point. For instance, reducing the speed from 130 to 120 km per h decreases consumption by 10%, while dropping to 110 km per h results in a 17% reduction.[65]
- **EVs, however, exhibit a consistent increase in consumption with speed,** and reducing speed limits can therefore have an even greater impact on their efficiency. For example, lowering the speed from 130 to 110 km per h can reduce consumption by up to 24%. This effect is also relevant in urban areas and on smaller rural roads, where speed reductions can significantly improve EV efficiency. Low speed limits in these environments (e.g., to 30 km per h) will therefore not only improve road safety, and facilitate a shift to cycling and walking, but also effectively reduce electricity use and emissions.

Exhibit 3.7

Speed greatly impacts efficiency: High speeds degrade ICE performance, while EV energy use increases proportionally with speed

Relationship between speed and energy consumption for passenger vehicles
km/h, LGE/100 km, kWh/100 km



ICEs: The direct impact of reducing the speed on the highway from **130 to 110 km/h corresponds to a fuel saving of 17%** per km driven.

EVs: The reduction in energy **consumption from 130 to 110 km/h is 24%** for electric cars, even more than for the current fleet of thermal vehicles

NOTE: LGE means litre gasoline equivalent.

SOURCE: Systemiq analysis for the ETC; Aurelien Bigo (2020), *Vitesse des déplacements : accélération au 20ème siècle, ralentissement au 21ème ?*; BonPote (2022), *10 reasons to lower speed limits on highways.*

65 Aurelien Bigo (2020), *Vitesse des déplacements : accélération au 20ème siècle, ralentissement au 21ème?.*

Box D

Speed limit reductions in the U.S: Public policies and corporate initiatives

Historically, national governments have implemented speed limit reductions to conserve fuel during crises, as in the 1973 oil crisis. In 1974, the US Congress imposed a "*National Maximum Speed Law*" limiting speeds of all vehicles to 55 miles per h (90 km per h) in response to the 1973 oil crisis which limited oil supplies and inflated fuel prices. This speed limit was relaxed in the late 1980s and finally repealed in 1995, when Congress returned responsibility for setting limits to the states.

Today, many countries use temporary speed limits to reduce congestion and air pollution, as well as improve road safety. In cities, these measures often combat local air pollution. Adopting similar policies for climate reasons could reduce overall fuel consumption by 2% almost immediately. However, recent discussions about reducing speed limits have encountered public resistance in France or Germany.

Today, most US states impose general speed limits of 70 or 75 miles per h (112 or 120 km per h), while some set the limit slightly lower for trucks. **Beyond government initiatives, consortia and private companies are also striving to reduce fuel consumption and emissions**. For many years, the American Trucking Association (ATA) has been campaigning for a national truck speed limit of 65 miles per h (105 km per h), partly for safety reasons but also to economise on fuel consumption. It argues that the "sweet spot" for US Class 8 trucks is 60–65 miles per h (95–105 km per h) and suggests that such a vehicle travelling at 65 rather than 75 miles per h, uses 27% less fuel.[66]

Some large US trucking companies, like Schneider, have independently reduced their fleet speed limits below state maxima. Schneider, for instance, lowered its fleet speed from 63 miles per h (101 km per h) to 60 miles per h (97 km per h), reducing annual fuel consumption by 17 million litres and emissions by 40 ktCO_2.[67]

Speed limits both on highways and more generally can therefore play a useful complementary role to electrification in driving energy efficiency. Overall, the adoption of eco-driving in highways and urban centres could lead to a fall of around 2.5 GtCO_2 in cumulative emissions[68]:

- The ETC estimates that a 20 km per h reduction in highway limits could reduce oil use by I Mb per d immediately and cumulative emissions by 2 GtCO_2 between now and 2050.[69]
- Similarly the IEA estimates that a 10 km per h speed reduction could reduce fuel use by 1.3% for passenger vehicles.[70,71]
- Imposing a 30 km speed limit in urban environments could reduce EV energy used by 5%, reducing cumulative emissions by 0.3 GtCO_2 for passenger vehicles and 0.2 GtCO_2 for commercial vehicles.

3.5 Impact of different levers on the annual rate of energy efficiency improvement

The energy productivity objective agreed at COP28 was expressed in terms of the annual rate of improvement in primary energy demand – specifically a doubling from around 2% per annum using 2022 as baseline to 4% by 2030. The IEA's efficiency tracker saw an improvement in energy intensity in passenger cars by 2% in 2023, compared to 1.6% average between 2010 and 2022. This is already a result of increased electrification (mainly in China) – even if it was partially counterbalanced by increasing weight and size of vehicles. In commercial vehicles, energy intensity remained close to 0.4% between 2010 and 2023.[72]

66 Alan C.McKinnon (2016), *Freight Transport Deceleration: Its Possible Contribution to the Decarbonisation of Logistics.*

67 Alan C. McKinnon (2016), *Freight Transport Deceleration: Its Possible Contribution to the Decarbonisation of Logistics.*

68 Cumulative emissions for the period between 2023 and 2050.

69 A 20 km per h speed limit reduction in highways, would reduce oil consumption by 500 kb per d for passenger vehicles and a total of 1 GtCO_2 of cumulative emissions for the period between 2023 and 2050. We have assumed a similar impact for commercial vehicles, without distinguishing per commercial vehicle types (light, medium, heavy).

70 In *A 10-Point Plan to Cut Oil Use*, the IEA estimates that reducing highway speed limits by 10 km per h could reduce oil demand by 290 kb per d for passenger vehicles and 140 kb per d for heavy trucks, resulting in a total reduction of 430 kb per d, or roughly 1.1% of total emissions from passenger and heavy commercial vehicles in 2023.

71 Although reducing speed from 130 km per h to 110 km per h could theoretically decrease fuel consumption by 16%, studies indicate that the overall impact is much smaller. Highways account for only 21% of road traffic, and the full 16% reduction is unlikely as some drivers already travel below the speed limit, and others may not adhere to the new limits. A French governmental study estimates that a 20 km per h reduction in highway speed limits would result in only a 2% decrease in overall passenger car fuel consumption. See Commissariat général au développement durable (2018), *Réduction des vitesses sur les routes Analyse coûts bénéfices.*

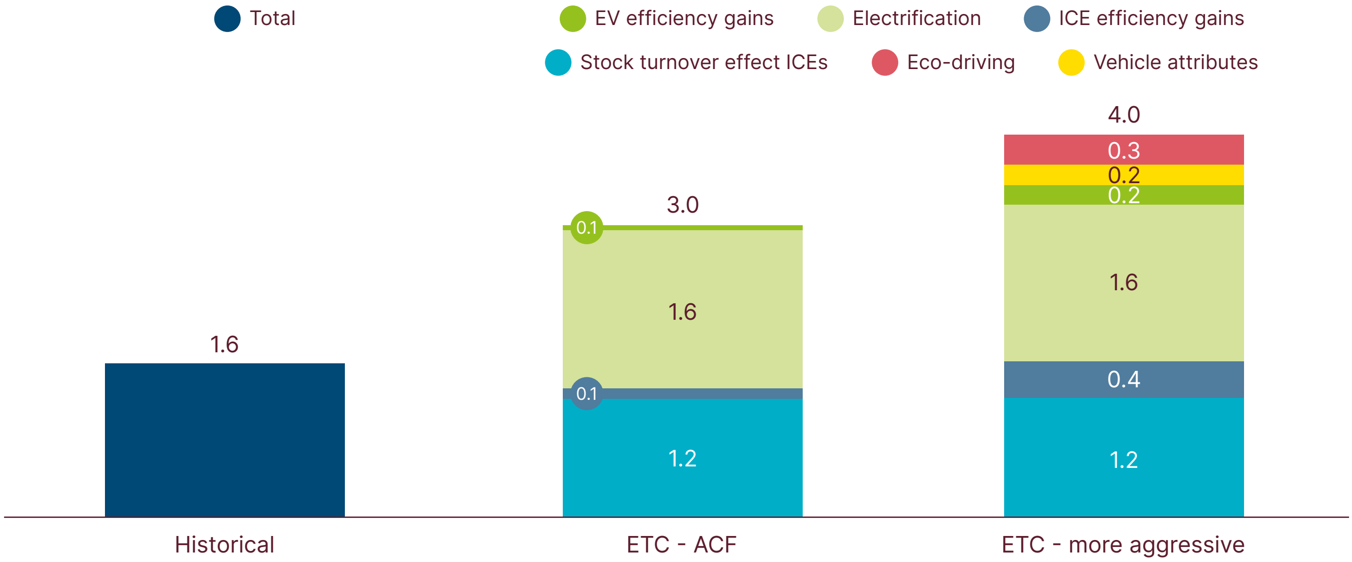
72 IEA (2024), *Energy Efficiency 2024.*

Exhibit 3.8

Passenger car energy intensity could improve by 3–4% annually, depending on policy ambition, mainly through fleet electrification and proper scrappage

Global energy intensity progress for passenger cars, between 2010 and 2020 and by scenario, between 2024 and 2030

%



2010–2020	2024–2030	
	• New ICE efficiency improvements: 0.7% p.a. • New EV efficiency improvements: 1.6% p.a.	• New ICE efficiency improvements: 2.5% p.a. • New EV efficiency improvements: 6% p.a. until 2035 • Ban on vehicles above 1,8 tonnes • 20 km/h speed limit on highways

NOTE: Past improvements were driven by an increase in the share of electric vehicles in fleets, continued improvements in engine technology and the introduction of hybrid powertrains. ACF = Accelerated but Clearly Feasible Scenario. This exhibit considers final energy demand.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

In this section, we therefore assess the impact of the measures considered so far on that metric; Exhibit 3.8, for example, shows the result for passenger cars. It starts on the left-hand side with a historic annual improvement rate of 1.6%, which derived from a combination of the stock turnover plus the increasing efficiency of new ICEs.[73]

- Over the next six years from 2024 to 2030, the stock turnover effect could deliver a 1.2% annual efficiency improvement, and new ICE efficiency gains a further 0.1 to 0.4% annual improvement.
- Electrification will, however, be the main driver of the increase in efficiency improvement, increasing the rate by 1.6%, and by an additional 0.1 to 0.2% if the efficiency of new EV could be increased above our base case assumption.
- Vehicle attribute changes (light weighting) and eco-driving (e.g., speed limits) could potentially deliver another +0.5% improvement in the annual rate in the more optimistic case.

73 We employed the Log-Mean Divisia Index (LMDI) method to determine each factor's contribution to these changes. The LMDI method, known for its simplicity and accuracy, decomposes changes in energy demand into specific factors, ensuring reliable results and clear interpretation of each component's impact, crucial for analysing fleet electrification, efficiency gains, and driving practices.

Service efficiency: A crucial yet difficult-to-measure lever

4

Service efficiency is one of the three areas of the ETC's energy productivity framework described in Exhibit 1.2. In the case of transport it covers the potential to:

- Reduce transport demand (i.e. km travelled) without compromising living standards.
- Shift transport demand to less energy / emission intensive modes (e.g., from four-wheel vehicles to bicycles or walking, or in the case of freight from road to rail).
- Increase vehicle utilisation and thus reduce vehicle kms travelled relative to passenger km travelled.

In principle, there are major opportunities for these "avoid and shift" actions to reduce energy demand, but with wide uncertainty over what can feasibly be achieved.[74] In this section we therefore:

- Introduce the set of "avoid and shift" actions.
- Estimate the potential impact on energy demand and cumulative emissions.

Our scenarios suggest that improved service efficiency could displace an additional 3 to 7 $GtCO_2$ of cumulative emissions, depending on the aggressiveness of global policy implementation.

4.1 "Avoid and shift" actions for road transport

Primarily "avoid" strategies which reduce the need for additional motorized travel include:

- **Increasing car occupancy rates via:**
  - **Congestion charges and road tolls**: Implementing fees and tolls can discourage single-occupancy vehicle trips, thereby reducing traffic and emissions.
  - **High-occupancy vehicle lanes**: Using incentives to reduce single-occupancy trips, such as high-occupancy toll lanes in some US cities or Jakarta's "three-in-one" rule, in which cars with fewer than three passengers were restricted to circulate in urban areas, can effectively promote carpooling and reduce traffic congestion.[75]
  - **Car sharing and car-pooling**: Innovative solutions like Ecov's carpooling lines, which allows people to join the carpool without an advance booking.[76]
- **Reducing transport demand via:**
  - **Accelerating the shift to remote work and online learning,** which would significantly reduce travel that would otherwise have to be made into an office or workplace, or university. This was stress-tested during the Covid-19 pandemic.
  - **Improving route optimisation for freight traffic.**[77] Utilising advanced routing algorithms and establishing logistics hubs to optimise delivery routes can minimise travel distances and fuel usage for commercial transport.
- **Where feasible and desirable, embracing higher-density development in cities**: Implementing concepts like Carlos Moreno's 15-minute city, which ensures that all essential services are within a 15-minute walk or bike ride from home, can reduce long commutes and lower carbon emissions.[78]

Primarily "shift" strategies aim to transition from high-impact modes of transport to more sustainable alternative such as public transport, lighter vehicles, and new mobility services. Key routes include:

- **Creating zero- or low-emission zones (ZEZs/ LEZs)**: Cities implementing ZEZs/LEZs reduce traffic and support transitions from ICEVs to zero-emission vehicles, encouraging shifts to walking, cycling, and public transport [see Exhibit 4.1].[79]

74 M. Arnz et. al (2024), *Avoid, Shift or Improve passenger transport? Impacts on the energy system;* World Resource Institute (2019), *Enhancing NDCs: Opportunities in Transport.*

75 The Guardian (2017), *Lessons from the fast lane: does this study prove car-pooling works?,* available at https://www.theguardian.com/cities/2017/aug/01/lessons-fast-lane-study-car-pooling-works-jakarta-google. [Accessed 10/04/2024]; Rema Hanna, Gabriel Kreindler, Benjamin A. Olken (2017), *Citywide effects of high-occupancy vehicle restrictions: Evidence from "three-in-one" in Jakarta.*

76 See *Faire de la voiture un transport collectif aux côtés des collectivités citoyens entreprises*, available at https://www.ecov.fr/.

77 Google Maps Platform, *Navigate more sustainably and optimize for fuel savings with eco-friendly routing,* available at https://mapsplatform.google.com/resources/blog/navigate-more-sustainably-and-optimize-fuel-savings-eco-friendly-routing/. [Accessed 10/04/24].

78 Z.Allam et. al (2022), *The '15-Minute City' concept can shape a net-zero urban future.*

79 ICCT (2023), *Planning and implementation of low- and zero-emission zones in cities.*

- **Implementing congestion pricing, fuel taxes and access restrictions**: Using congestion pricing, fuel taxes, access restrictions and increased parking fees can encourage shifts towards public transport and cycling.
- **Scaling cycling and micromobility**: Investing in cycling infrastructure and initiatives can promote cycling as a viable alternative to driving. For example, Paris' Plan Velo Act 2 aims to make the city fully cyclable by 2026, including bike purchase subsidies, car-free streets and higher parking fees for polluting vehicles.[80] This strategy is also applicable in the US, where over 50% of weekly vehicle trips in the ten most populous cities are under five miles.[81]
- **Improving public transport and integrated mobility** policies in cities, with particular focus on accessibility and safety, fare integration and concession policies. For example, the Station Access and Mobility Program (STAMP) in India enhances metro rail efficiency by integrating it with other transport networks, implementing solutions like electric autorickshaws and carpooling apps to improve station accessibility.[82]

Both "avoid and shift" policies can also play an important role in reducing traffic congestion.

Exhibit 4.1

Big European cities are enforcing measures to reduce demand for polluting ICEs and incentivise modal shift towards cleaner transport modes

Oslo NORWAY
- Planning to establish a ZEZ in the city centre area, overlapping with the car-free zone.

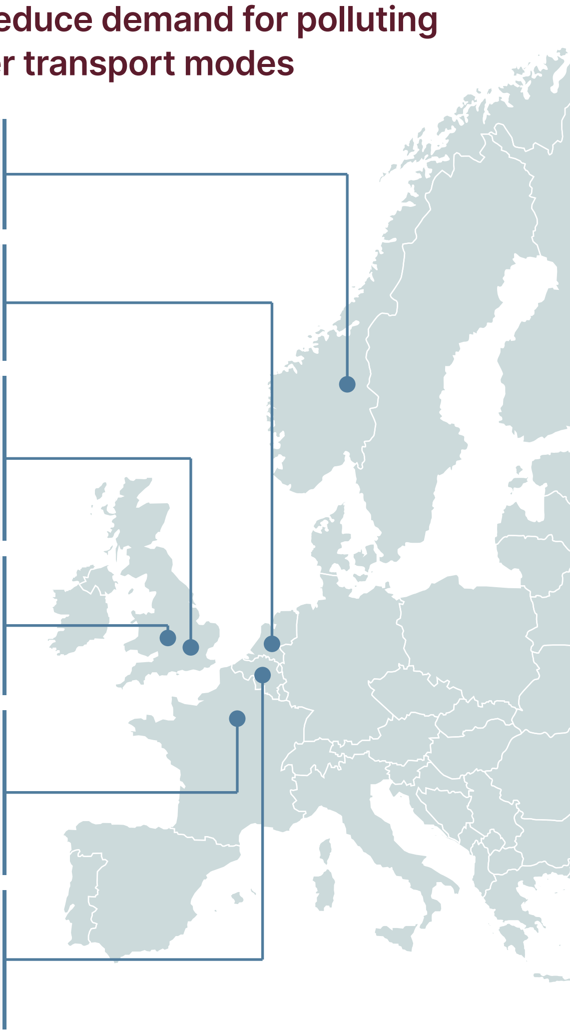
Amsterdam THE NETHERLANDS
- Remove >10,000 parking spaces by 2025.
- Bicycle Plan of €54 million between 2017 and 2022.

London UNITED KINGDOM
- In 2017, the mayor introduced a £42 million taxi delicensing scheme to scrap older diesel taxis for zero-emission capable vehicles.
- With the planned expansion of the ULEZ, the city introduced a new £110 million vehicle-scrappage scheme.

Oxford UNITED KINGDOM
- Reduce car trips by a quarter by 2030 and achieve net-zero transport by 2040.
- City plans to install more ZEZ enforcement cameras.

Paris FRANCE
- Recently allocated €250 million for 180 km of new cycling roads and over 130,000 new bicycle parking spaces.
- Government offers up to €4,000 to low-income households in the LEZ for swapping their old ICE for e-bikes.

Brussels BELGIUM
- Good Move plan aims to reduce private car use by 24% in Brussels.
- Bruxell'Air scheme offers a bonus for scrapping a car in exchange for active modes, public transport or car sharing.



NOTE: LEZ = Low emission zones, ZEZ: Zero-emission zones.

SOURCE: Systemiq analysis for the ETC; The ICCT (2023), *Planning and implementation of low- and zero-emission zones in cities.*

80 BNEF (2024), *NetZero Pathfinders Quarterly.*

81 RMI (2023), *This E-Bike Impact Calculator Can Help Cities Accelerate E-Bike Adoption.*

82 The programme started in 2017 after a lower-than-expected commuter usage. Since its inception, the programme has expanded to multiple cities, engaging over 45 companies and piloting 11 solutions with 10 startups. These efforts have facilitated over 50,000 last-mile trips to metro stations, saving more than 240,000 passenger minutes compared to less efficient modes. See World Resources Institute, *Station Access and Mobility Program (STAMP)*, available at https://www.wri.org/initiatives/station-access-and-mobility-program-stamp.

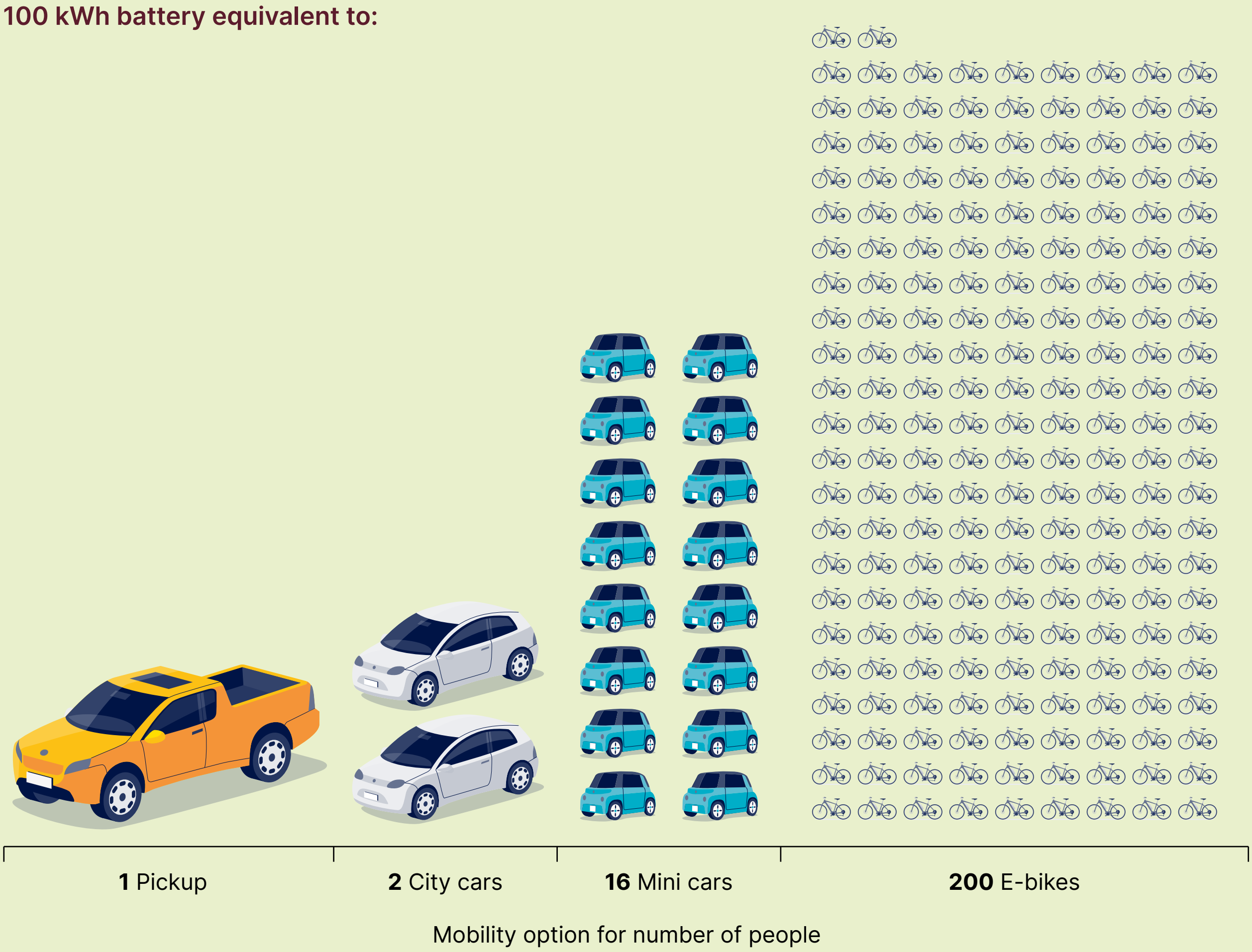
Box E

The importance of shifting to alternative, lighter vehicle modes

Promoting alternative and lighter vehicles like e-bikes not only reduces emissions and the number of vehicles on the roads but also impacts material consumption. For instance, 200 e-bikes consume the same energy and battery resources as a single pickup truck, underscoring the need to transition from an auto-centric world to more sustainable, efficient transportation options [Exhibit 4.2].[83]

Exhibit 4.2

Use of lighter vehicles reduces emissions & material consumption



SOURCE: Systemiq analysis for the ETC.

83 Bon Pote (2023), *Les véhicules intermédiaires : l'avenir de la mobilité?.*

4.2 Estimating the potential impact

Estimating the impact of such policies is extremely challenging, since it depends both on the degree of political support for public policy incentives and uncertain judgments on how individuals will respond. In addition, there is an important distinction between levers which could produce short-term impacts and those that require longer-term policy support and investment:

- **Feasible short-term actions include** measures such as encouraging remote work, implementing car-free Sundays in cities and alternating allowed car usage into certain zones on particular days. In 2022, the IEA estimated that such short-term actions could reduce road transport oil demand by 4% in just four months [Box F].
- **Longer-term strategies include** those dependent on, for instance**,** urban planning (e.g., to achieve a "15 minute city"), rail and other mass transit investments, or cycling lane development. These actions can have impacts of several years and in some cases decades.

Various studies have illustrated that, in principle, "avoid and shift" measures could deliver very significant reductions in transport demand:

- **The IEA's *Net Zero* report suggests, for instance, that** in urban areas, 20–50% of all car trips could shift to public transport, ridesharing, walking, and cycling.[84] Car ownership could also be reduced by 35% with adequate public transport services and ridesharing schemes.
- **The ICCT's** recent report, *Vision 2050, Strategies to Align Global Road Transport with Well Below 2°C*, suggests that "avoid and shift" levers could reduce global passenger car travel by 37% before 2050 compared to the baseline scenario.[85]

But political opposition to the required supporting policies and inadequate investment could mean that actual demand reductions are much smaller. We have therefore considered a scenario expecting "avoid & shift" levers to reduce demand for passenger vehicles by 18% by 2050.[86] **This would result in a cumulative 3 GtCO$_2$ emissions reduction from passenger cars.**[87] In a more aggressive case, we estimate that the impact on demand for passenger vehicles could fall by 36%.

The impact of "avoid and shift" strategies in commercial transport is not considered in this report and will be discussed in the next chapter on autonomous vehicles, where commercial vehicles are expected to achieve some efficiency gains.

Exhibit 4.3 shows the impact on cumulative emissions of these service efficiency scenarios relative to the other levers already considered. Compared with the impact of electrification and energy process efficiency improvements, which could together reduce emissions by 91 GtCO$_2$, the saving of a total 3 GtCO$_2$ is relatively small. This reflects the fact that once electrification and electricity decarbonisation have been achieved, emissions are already sufficiently low making a further reduction have a limited effect.

But this eventual impact on long term emissions understates the importance of pursuing service efficiency improvements since:

- An 18% reduction in transport demand in 2050 – considered in our realistic scenario – would equally reduce electricity demand by the same amount, therefore reducing the investment needed to build a zero-carbon electricity system.
- Early implementation of service efficiency improvements could achieve vitally important short-term emissions reductions.
- The measures which will deliver service efficiency improvements will also deliver reduced traffic congestion, improved local air quality and improved health.

84 Figure 9 from IEA (2021), *Net Zero by 2050*.

85 ICCT (2023), *Vision 2050 Strategies to align global road transport with well below 2°C*.

86 This vision does not include considerations on decreasing populational growth and loss of purchase power that could influence the buying decision of younger generations – those are underlying considerations in our baseline projections of passengers vehicle demand.

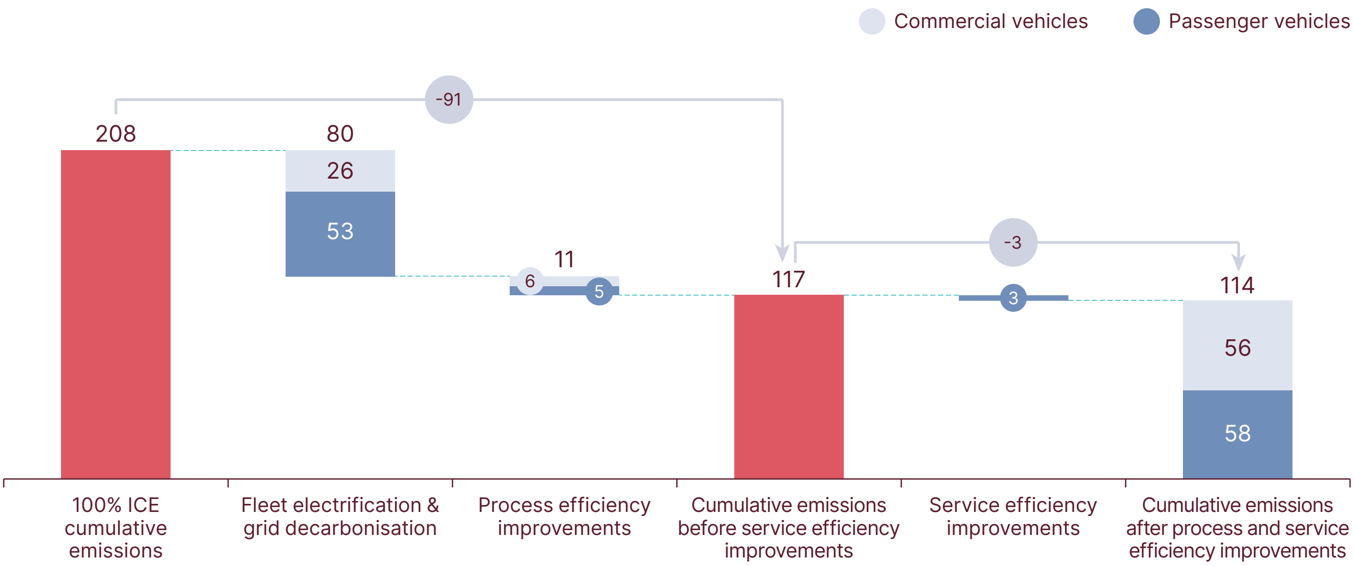
87 Cumulative emissions for the period between 2023 and 2050.

Exhibit 4.3

Combining electrification, energy process and service efficiency, levers could reduce road sector emissions from 208 $GtCO_2$ to 114 $GtCO_2$

Projected cumulative CO_2 emissions between 2023 and 2050 in a full ICE scenario vs. with energy productivity levers

$GtCO_2$



NOTE: All ICE means Internal Combustion Engine Vehicles, EV means Electric Vehicles. We consider that the combustion of a barrel of oil equivalent results ~405 kg CO_2.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

Box F

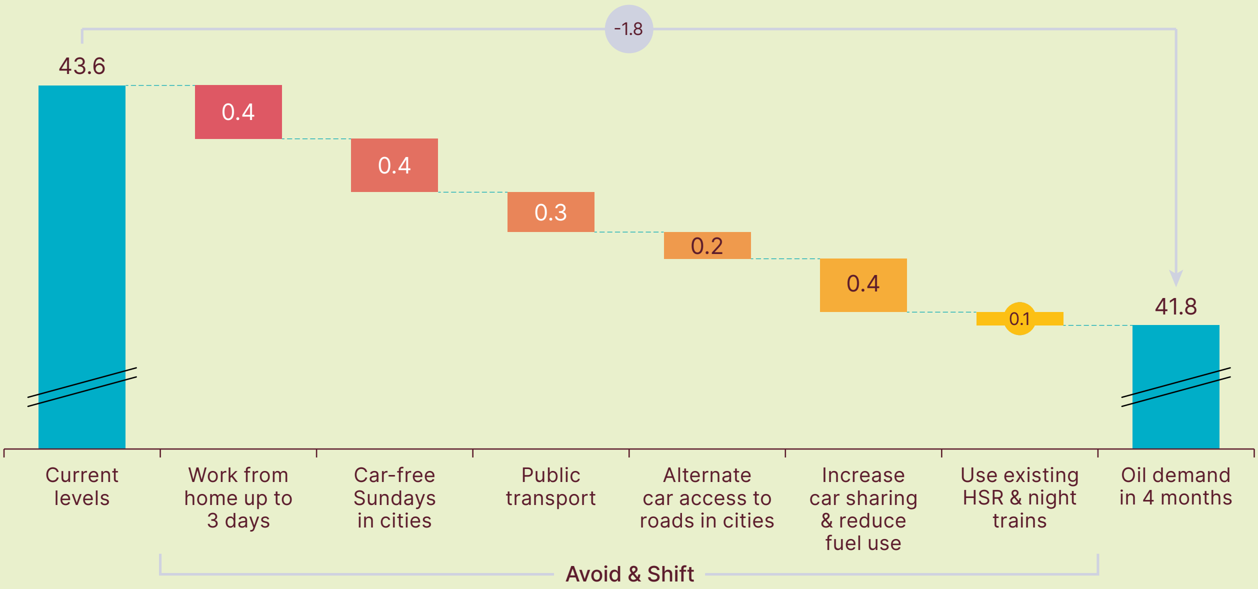
Feasible short term measures to reduce road transport demand

The IEA's *10-Point Plan to Cut Oil Use in 2022*, created in response to the global energy crisis triggered by Russia's invasion of Ukraine, proposed ten immediate actions to reduce oil demand. These measures, including speed limits, remote work, car-free Sundays, public transport subsidies, increased car sharing, and alternating car access in cities, could potentially displace around 1.8 Mb per d overnight.[88]

Exhibit 4.4

Avoid & shift levers could displace ~1.8 Mb/d overnight according to the IEA

Oil demand reductions in advanced economies within four months in the IEA's 10-Point Plan, 2022
Mb/d



NOTE: In the face of the emerging global energy crisis triggered by Russia's invasion of Ukraine, the IEA's 10-Point Plan to Cut Oil Use proposes ten actions that can be taken to reduce oil demand with immediate impact – and provides recommendations for how those actions can help pave the way to putting oil demand onto a more sustainable path in the longer term. Only six points related to avoid & shift in passenger road transport are highlighted. HSR = high-speed rails.

SOURCE: IEA (2022), *A 10-Point Plan to Cut Oil Use.*

88 IEA (2022), *A 10-Point Plan to Cut Oil Use.*

Autonomous vehicles: Impact across energy process and service efficiency

5

The potential for autonomous vehicles (AVs) to disrupt mobility is significant, sparking considerable debate. By definition, AVs represent a transformative advancement in transportation technology, characterised by their ability to navigate and operate without human intervention. AVs are categorised by levels of autonomy, with Level 4 and Level 5 being the most advanced:

- Level 4 autonomy allows vehicles to operate independently in specific conditions and environments, such as urban areas or highways, but may require human intervention in certain situations.
- Level 5 autonomy, the pinnacle of AV technology, enables vehicles to function entirely autonomously under all conditions, eliminating the need for a driver altogether.

These advancements hold significant potential to reshape mobility, offering benefits such as improved safety, reduced traffic congestion and enhanced accessibility.

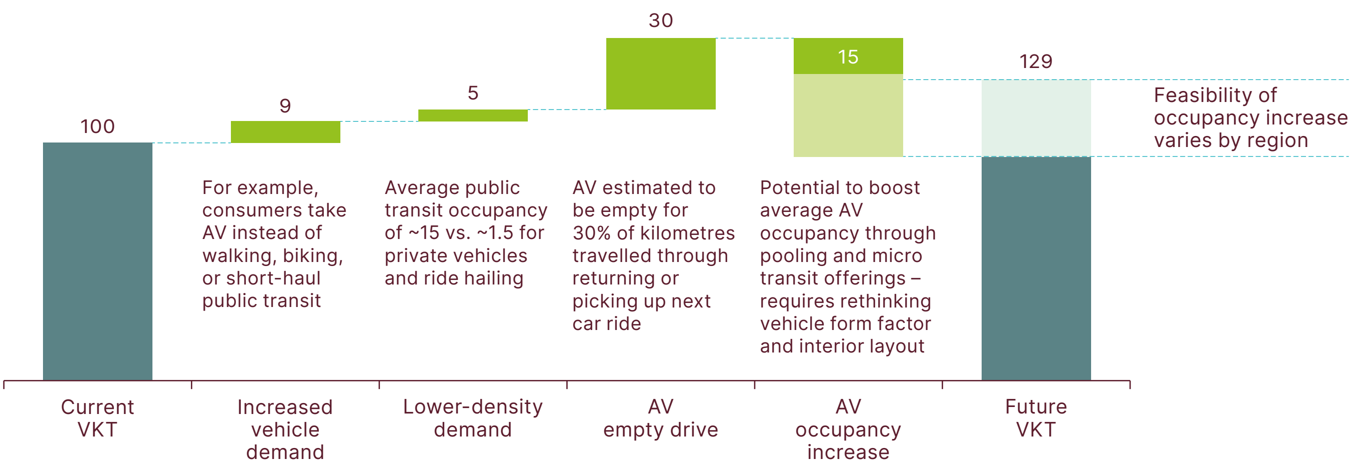
The crucial question is whether AVs will facilitate a transition to decarbonised mobility or introduce unwanted effects such as increased vehicle use. Research and expert interviews indicate that, as shown in Exhibit 5.1:

- The impact on passenger road safety and traffic volumes is uncertain and will depend heavily on effective policies designed to drive specific applications of AV technology.[89]
- AV technology is likely to deliver a reduction in commercial vehicle energy use.
- For both passengers and commercial, AV energy productivity is heavily dependent on the evolution of software, hardware, and network. As of today, cloud computing in AVs consumes more energy that any productivity gain. But this may not be the case by 2050.[90]

Exhibit 5.1

Autonomous vehicles may increase overall transport demand due to empty rides, creating an ambivalent impact on total kilometres driven

Current and future vehicle kilometres travelled (VKT) given impact of AVs
VKT



NOTE: AV refers to autonomous vehicles; Pooling refers to rides shared with other passengers.

SOURCE: Systemiq analysis for the ETC; BCG (2022), *Shared, Autonomous, and Electric: An Update on the Reimagined Car.*

89 BCG (2022), *Shared, Autonomous, and Electric: An Update on the Reimagined Car.*

90 Agora (2021), *Auto tankt Internet.*

5.1 Autonomous passenger vehicles: Uncertain impact on demand

The impact of AVs on passenger road transport demand and energy use may be fairly neutral, given competing effects that may increase and decrease overall energy demand [Exhibit 5.1].

There are three effects which could increase demand:

- **Reverse modal shift**: Consumers might prefer AVs over low-emission transport modes such as walking, biking or short-haul public transport, increasing overall energy use.
- **Lower-density demand**: Unregulated AV fleets could replace public transit for short trips, exacerbating congestion.
- **Empty drives:** AVs might be empty for approximately 30% of kilometres travelled, either returning or picking up the next ride, particularly in the case of robo-taxis. However, AV experts believe that optimised routing software will mitigate the issue of empty miles, given the profitability focus of robo-taxi fleet managers.

However, AVs also hold the potential for numerous positive impacts:

- **Increasing occupancy rate**: Shared AVs could increase car sharing, raising the average occupancy rate of passenger cars from the current 1.1 passengers per car in Europe, thus reducing total vehicle km travelled. According to Boston Consulting Group (BCG), about half of all AVs will be communal rather than privately owned, offering greater convenience than conventional mass transit.[91]
- **Enhance driving efficiency**: AVs can improve driving efficiency by eliminating human error, resulting in safer, more efficient operations and reduced journey and wait times.
- **Modal shift**: AVs can support first-mile and last-mile trips, connecting suburban areas to public transportation networks and promoting multimodal journeys over single-mode car trips. Some estimates suggest this could reduce traffic volume by 4%, as shared transportation modes decrease the number of vehicles on city streets and optimise traffic flows.[92]

The impact of AVs will therefore largely hinge on policy decisions and urban strategies, including how regulation of AVs is combined with support for**:**

- Micromobility solutions to address door-to-door transport demand.
- Investments in mass transit networks and a strong modal shift.

City planners will need to decide which types of AV to license, between, for instance, robo-pods (up to two passengers), robo-taxis (up to five passengers), or robo-shuttles (up to 15 passengers). Robo-shuttles are more likely to be the most sustainable option by complementing public transport and ensuring high occupancy rates.[93]

91 BCG (2020), *Can Self-Driving Cars Stop the Urban Mobility Meltdown?*.

92 BCG (2020), *Can Self-Driving Cars Stop the Urban Mobility Meltdown?*.

93 Robots could drive at the optimal level of energy use.

Given these conflicting possible effects, the scenarios presented in the ETC's report on *Fossil Fuels in Transition: Committing to the Phase-down of All Fossil Fuels* assumed that shared robo-taxis could by 2050 account for a third of vehicle km travelled (with around 150 million robotaxis, travelling 70,000 km per year each, and meeting a demand for 10,000 billion vehicle km), and would therefore reduce the size of the total passenger vehicle fleet by 25%. However, this would not have any implications for total vehicle km travelled, and therefore, no implications for energy demand [Box G].[94]

Box G

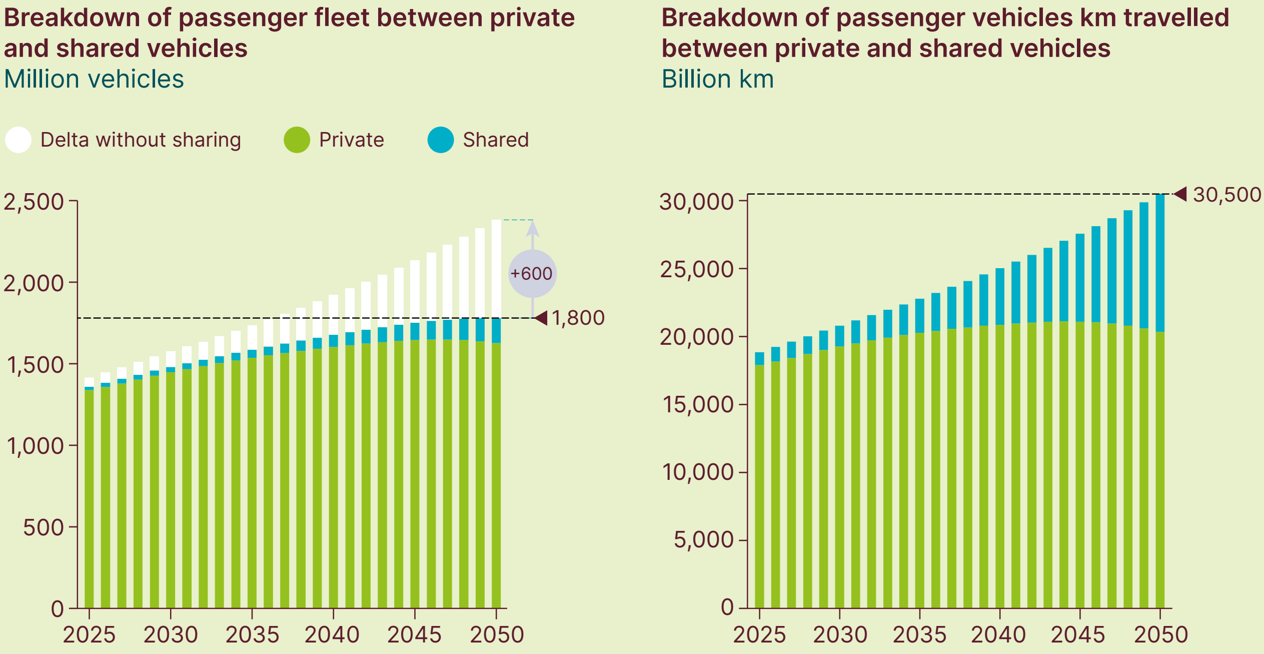
Autonomous vehicle assumptions in the ETC's *Fossil Fuels in Transition* report

Car sharing and robo-taxis can significantly reduce car ownership, potentially downsizing the global passenger car fleet from 2.4 billion to 1.8 billion. As highlighted in the ETC's *Fossil Fuels in Transition: Committing to the Phase-down of All Fossil Fuels* report, while the demand for passenger transport is expected to grow linearly, fewer vehicles will be on the road from 2035 onwards as AVs operating 24/7 will offer a door-to-door service. This shift will replace individual car ownership and reduce the number of cars in cities.

The fleet of AVs (robo-taxis with autonomy Level 4 or more) may begin to replace km travelled by ordinary private and shared EVs in the 2030s [Exhibit 5.2]. The electricity demand from these vehicle groups would grow to around 40% of demand in 2050 from less than 1% in 2030.

Exhibit 5.2

Passenger car fleet and vehicle km travelled breakdown



NOTE: Same fleet and vehicle km breakdown for both Accelerated but Clearly Feasible (ACF) Scenario and Possible but Stretching (PBS) scenarios.

SOURCE: Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*.

94 We disregard in this analysis any reduction of embodied emissions that may come from a reduction in vehicle fleet.

5.2 Autonomous commercial vehicles: Potential for significant energy saving

Autonomous commercial vehicles have the potential to enhance efficiency and sustainability through various operational improvements. **According to energy research firm Aurora,[95] autonomous trucking can potentially achieve 13–23% net energy efficiency improvement per loaded km.** Key areas of improvement include:

- **Energy process efficiency:**
  - **Vehicle attributes:** Removing human-centric features and optimising vehicle design for autonomous operation can reduce weight and improve aerodynamics. The removal of human drivers allows, for instance, for lighter, more aerodynamic truck designs and reduces idling time, further saving energy.[96] Additional fuel savings can be realised by changing the truck's design. As the driver is absent, the truck's cabin can be completely redesigned. This, together with other design modifications made possible by automation (such as the absence of heating and air conditioning on board) can contribute to lowering the weight and improving both the aerodynamics and the vehicle performance.[97]
  - **Limiting highway speeds:** Autonomous commercial vehicles can drive more consistently at optimal speeds, reducing fuel consumption by maintaining lower speeds without the pressure of limited driving hours (see section 3.3).[98]
  - **Eco-driving:** Autonomous trucks can consistently apply optimal driving techniques, such as efficient acceleration, braking, and coasting to save fuel. For example, these optimised driving patterns can achieve up to 9.5% fuel savings according to a 2015 study in the Netherlands by Thijssen, Hofman, and Ham.[99]
- **Service efficiency:**
  - **Reducing idling:** Autonomous trucks eliminate the need for driver rest breaks, significantly cutting down on idle time and fuel wastage.[100] For instance, in the U.S. reducing idling can save up to 1,500 gallons of diesel annually, which translates to a 9% reduction in fuel consumption.[101]
  - **Deadhead reduction:** By optimising logistics and waiting for the next load at optimal locations, autonomous trucks can minimise empty miles, thus reducing overall fuel use. This approach can significantly decrease deadhead miles, which currently account for about 15% of truck mileage in the U.S.[102]
  - **Off-peak driving:** Autonomous trucks can operate nearly 24/7, significantly increasing vehicle utilisation and reducing operational costs by shifting to low congestion times.[103]

Similar to passenger vehicles, while autonomous commercial vehicles offer numerous benefits in efficiency and sustainability, potential rebound effects must be considered. For example, reduced road freight transport costs due to driverless technology could increase road freight transport demand,[104] increasing the share of road freight compared to more sustainable modes like rail or shipping. Additionally, the onboard automation systems in autonomous trucks consume energy, partially offsetting fuel savings from eco-driving and reduced idling. The power draw from sensors, computing hardware, and communication systems can increase the vehicle's energy demand by up to 1.5%.[105]

As a result, there is considerable uncertainty over the net effect of autonomous trucks on fuel efficiency, but the balance seems likely positive. An academic paper by Engholm et al. considers three scenarios in their analysis of operating costs.[106]

- **Base scenario**: Driverless trucks achieve a 10% fuel saving due to eco-driving and lower speeds.
- **Pessimistic scenario**: Fuel efficiency remains unchanged as the benefits of eco-driving are completely offset by the energy consumption of the onboard automation system and increased freight transport demand.

95 Aurora (2024), *The Sustainable Opportunity of Autonomous Trucking.*
96 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
97 Transport and environment report (2022), *Digitalisation in the mobility system: challenges and opportunities, Annex 3 Autonomous freight transport.*
98 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
99 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
100 Idling time is attributed to where the driver is sleeping, eating, working, or relaxing in his or her vehicle when they are not driving.
101 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
102 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
103 It is also worth noting that some of these benefits could occur without a fully autonomous commercial vehicle, with some level of connected services (e.g., real-time traffic forecasting for optimised routes), see more on ALICE (2024), *AI in Logistics.* Furthermore, AD and ADAS systems and their offboard computing centres could lead to increased energy consumption, which would reduce overall efficiency.
104 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
105 Aurora (2024), *The Sustainability Opportunity of Autonomous Trucking.*
106 Engholm et al. (2020), *Impacts of large-scale driverless truck adoption on the freight transport system.*

- **Optimistic scenario**: Projects a 20% fuel saving, attributed to eco-driving, lighter truck designs, high platooning rates[107] and low energy consumption by the automation system.

Regardless of the precise impact of AVs on commercial freight demand and energy use, it will increase gradually over time:

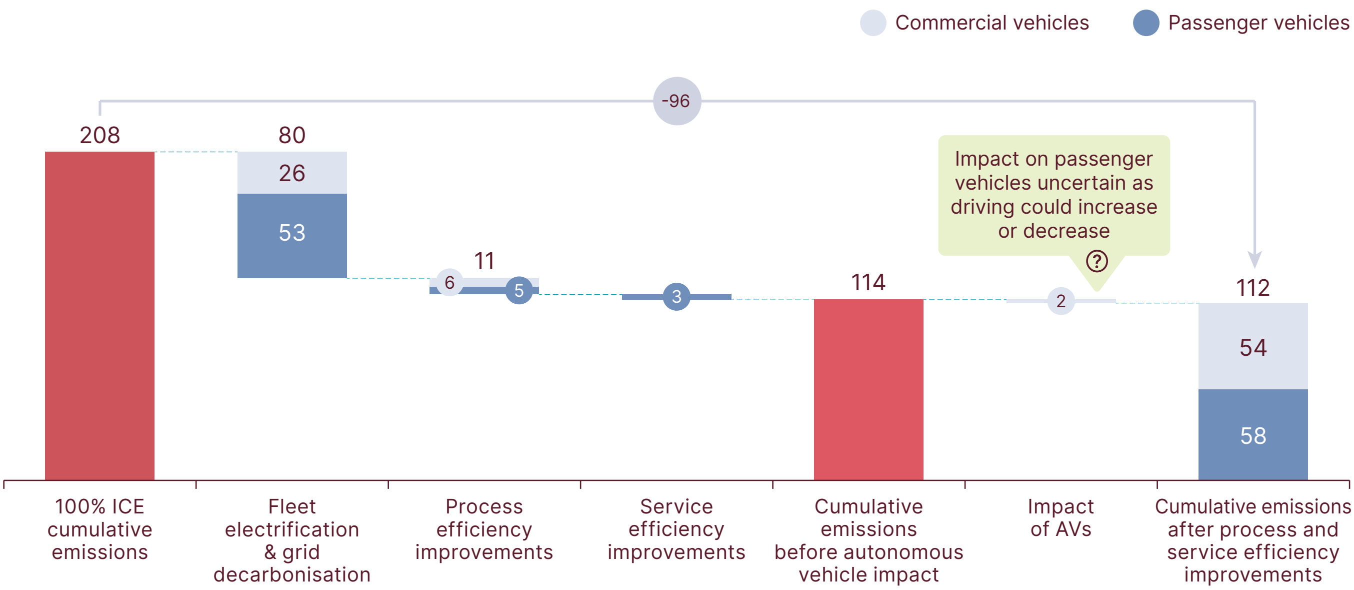
- From 2023 to 2030, minimal automation advancements are anticipated globally. However, we expect a proliferation of Level 2 and Level 3 automation (partially automated systems). These systems could enhance driving efficiency by 5% for all new vehicles (both ICE and EVs) by 2030.[108]
- Post-2030, we foresee a growing number of trucks being equipped with Level 4 and Level 5 autonomy. By 2040, combining multiple strategies (such as vehicle attribute changes, eco-driving practices and route optimisation) could yield a 20% efficiency improvement in new vehicles. These changes will be applied to new EVs.
- From 2040 onwards, the ETC assumes that all new electric commercial vehicles will be equipped with Level 4 and Level 5 autonomy and will be 20% more efficient than their theoretical non-automated EV counterparts.

These assumptions result in the 2 $GtCO_2$ of cumulative emission reductions [Exhibit 5.3]: [109,110]

Exhibit 5.3

Combining electrification, process energy and service efficiency levers, and autonomous vehicles could reduce road sector emissions from 208 $GtCO_2$ to 112 $GtCO_2$

Projected cumulative CO_2 emissions between 2023 and 2050 in a full ICE scenario vs. with energy productivity levers
$GtCO_2$



NOTE: All ICE means Internal Combustion Engine Vehicles, EV means Electric Vehicles. AVs = Autonomous Vehicles. We consider that the combustion of a barrel of oil equivalent results ~405 kg CO_2.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

107 A platooning rate refers to the percentage of time or distance a vehicle spends traveling in a platoon. A platoon is a group of vehicles (often trucks or AVs) that travel closely together using vehicle-to-vehicle (V2V) communication to improve efficiency, reduce fuel consumption, and enhance safety.

108 Morgan Lewis (2023), *The five-year outlook on ADAS level 2, 3, and 4 technologies in passenger vehicles and commercial trucks.*

109 The likelihood of adoption of commercial AVS are embedded in ETC's hypothesis described above.

110 Cumulative emissions for the period between 2023 and 2050.

Summary conclusions

6

Electrification and the decarbonisation of electricity supply will be by far the most important drivers of energy productivity improvement in the road transport sector. But it is also important to pursue improvements in energy process efficiency, and to maximise service efficiency improvements in order to deliver early emissions reductions and to reduce the electricity supply required for road transport in 2050 and beyond.

This conclusion holds whether we look at:

- Total energy demand measured either at the final or the primary level.
- The annual rate of improvement in energy efficiency between now and 2030.
- Cumulative CO_2 emissions between now and 2050.

Final and primary energy demand

Exhibit 6.1 shows the potential impact of different energy productivity improvement levers between now and 2050 for road transportation and at the final energy demand level:

- Today's total of 23,600 TWh of final energy demand could grow to 38,800 TWh by 2050 in a 100% ICE scenario, with the beneficial impact of the stock turnover effect offset by rising demand for passenger road services.
- Electrification itself would reduce this by 19,900 TWh (50%) but accelerated improvements in EV technical efficiency, together with some ICE efficiency gains, light–weighting, and efficient driving could reduce demand further to 10,500 TWh, a close to 75% reduction.
- Service efficiency improvements – via the "avoid and shift" measures considered in Chapter 4, could deliver a further 2,800 TWh reduction, with 2050 final energy requirements of 7,700 TWh down 80% from the 100% ICE case.

This makes it clear that electrification and improvements in the technical efficiency of EVs are critical. However, lightweighting, eco-driving and "avoid and shift" actions could together further reduce the final energy requirement from 11,900 TWh to 7,700 TWh. This would reduce total energy input by 65% to power an almost entirely electric fleet, and as a result, reduce the investment required for zero carbon power capacity and the land use requirements for renewable energy. Avoid and shift measures, in particular, would also deliver significant benefits in terms of congestion.

Considering the impact on primary energy demand, the scale of opportunity is similar [Exhibit 6.2] - with 45,600 TWh of energy in the 100% ICE case reduced to 9,000 TWh by 2050. The slightly higher 2050 figure at the primary energy level reflects the fact that there will still be some remaining conversion loss from small residual fossil fuel power generation. These would further reduce over time beyond 2050.

Annual rate of energy productivity improvement

Chapter 3 showed for passenger cars an estimate of the potential increase in the annual rate of energy efficiency improvement which could result over the next six years from the combination of electrification, improvements in vehicle technical efficiency, lighting weighting and more energy efficient driving.

This combination of effects could produce an acceleration in the reduction of energy use per km travelled from 1.6% per annum to as much as 4% per annum in the more aggressive case [See Exhibit 3.8 in Chapter 3].[111] Service efficiency improvements which reduce kilometres travelled would not increase this specific measure, since they reduce both the numerator and the denominator of the calculation.

But if energy productivity were measured at the level of energy use per unit of GDP, service efficiency improvement could deliver a further increase above the 4% per annum.

Specifically, our analysis assumes that by 2050, service efficiency improvements could reduce final energy demand by 18%, with a 4% reduction achieved by 2030. This 4% reduction by 2030 reflects our assessment of what is likely to be politically feasible. This is significantly less than IEA's normative net-zero scenario which points to, in principle, a 15% reduction in private car use with sufficient ambitious policies.[112]

111 ACF and the more aggressive scenarios portray the lower and upper boundaries for road transport energy intensity improvements; our analysis in Chapter 3 falls between these two scenarios.

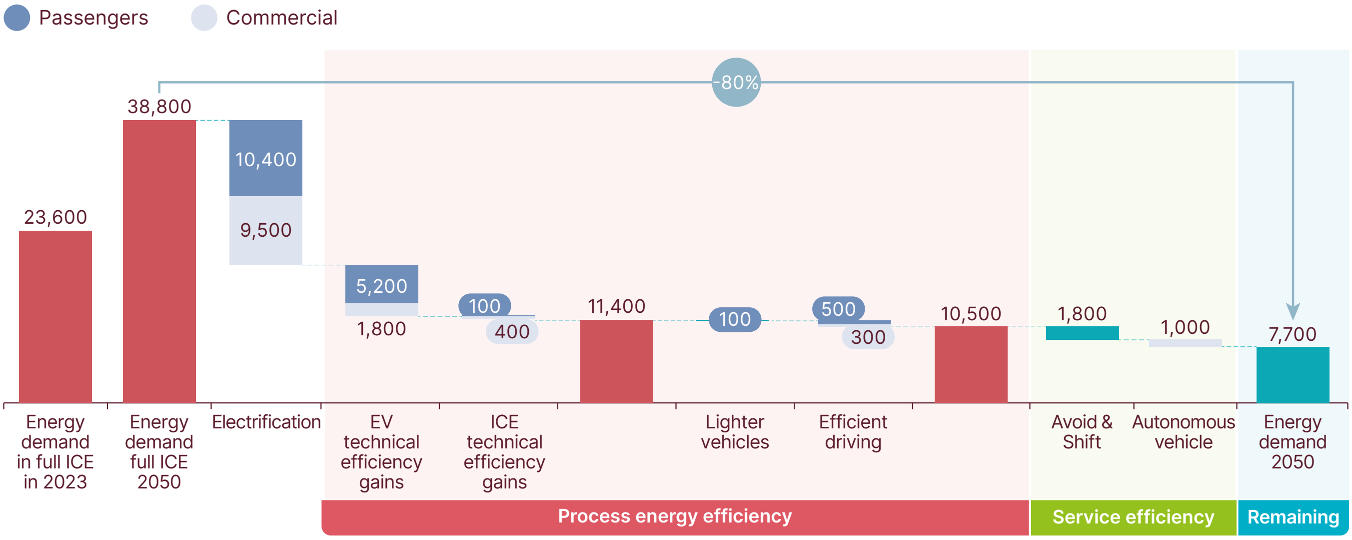
112 IEA (2021), Net Zero by 2050: *A Roadmap for the Global Energy Sector.*

Exhibit 6.1

Switching to electrification is the most crucial factor in reducing energy consumption for road transport by 2050

Final energy demand in 2050 and impact of energy productivity levers

TWh



NOTE: ICE means Internal Combustion Engine Vehicles, EV means Electric Vehicles. Productivity levers: 20% efficiency gains for ICEs by 2050, 50% efficiency gains for EVs by 2035, 20 km/h speed limit reduction on highways and 30 km/h speed limit in urban areas, 36% demand reduction by 2050 through avoid & shift levers. Final energy demand attributed by lever with LMDI (logarithmic mean divisia index) methodology. For primary energy demand, energy efficiency of 85% from fossil fuel extraction to tanker, and for renewables power (e.g., electricity conversion and transmission losses) is taken.

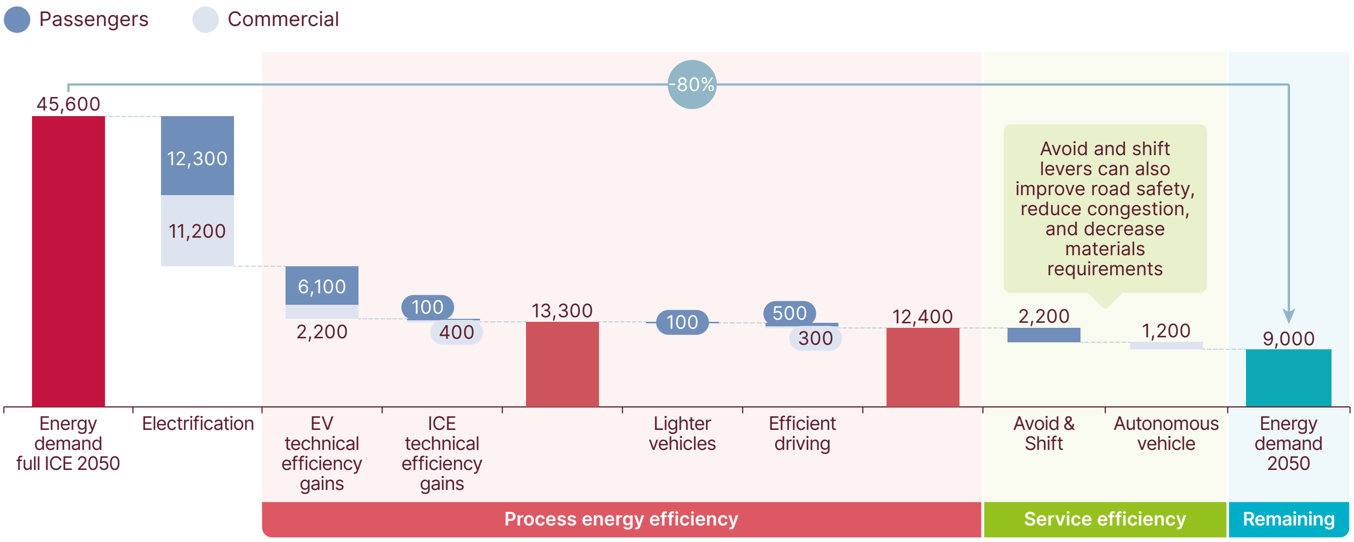
SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

Exhibit 6.2

Switching to electrification is the most crucial factor in reducing energy consumption for road transport by 2050

Primary energy demand in 2050 and impact of energy productivity levers

TWh



NOTE: ICE means Internal Combustion Engine Vehicles, EV means Electric Vehicles. Productivity levers: 20% efficiency gains for ICEs by 2050, 50% efficiency gains for EVs by 2035, 20 km/h speed limit reduction on highways and 30 km/h speed limit in urban areas, 36% demand reduction by 2050 through avoid & shift levers. Final energy demand attributed by lever with LMDI (logarithmic mean divisia index) methodology. For primary energy demand, energy efficiency of 85% from fossil fuel extraction to tanker, and for renewables power (e.g., electricity conversion and transmission losses) is taken.

SOURCE: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*

Policies to achieve *"avoid and shift"* effects should therefore be pursued as aggressively as possible as a means to achieve the early reductions in emission which are needed to limit global warming to 1.5 °C, even if their impact on eventual final and primary energy demand is dwarfed by the electrification effect.

Implications for cumulative CO_2 emissions

Exhibit 5.4 in Chapter 5 sets out the impact of the different levers on cumulative CO_2 emissions between now and 2050, covering both passenger and commercial vehicle fleets.

Here too, electrification is by far the most important driver, but this analysis also highlights the vital importance of grid decarbonisation. Electrification without power system decarbonisation would deliver only half of the potential 79 $GtCO_2$ cumulative emission reduction. Nevertheless, while managing additional emissions from electricity generation for EVs is important, the overall emissions reductions from transitioning to EVs will far exceed these increases in a global scale. Only a few countries with currently high carbon intensity power systems could fail to deliver any emission reduction benefits.[113]

6.1 Actions to deliver required productivity gains

This section summarises the key actions argued for in this report, categorised by stakeholder. The aim is to highlight strategies for fleet electrification, vehicle scrappage, process energy efficiency, service efficiency, and AVs, alongside cross-cutting measures.

> **Fleet electrification and grid decarbonisation** should remain critical priorities for all stakeholders, especially policymakers.

Policymakers:

- **Set and maintain ambitious objectives:**
  - Uphold the ICE sales ban in the EU by 2035 (and avoid loosening it to include e-fuels) and other strong standards across the globe. Introduce similar sales bans and/or restrictions where missing.
  - **Grid decarbonisation targets for 2030–2040:** Establish specific goals to reduce grid carbon emissions by increasing renewable energy sources by 2030–2040.
- **Approve investments in grid expansion and reinforcement:** Assess future energy demand and prioritise upgrades that enhance reliability and integration of renewable energy, streamline regulatory approvals and allocate funding to modernize grid infrastructure.
- **Fuel economy standards**: Strengthen reliable fuel economy standards for all vehicle types to ensure continuous improvements in energy efficiency.
- **Implement fair taxation**: Increase taxation on ICE vehicles, ensuring measures are fair to avoid backlash, as seen in France with the gilets jaunes.[114]
- **Develop charging infrastructure**: Invest in fast chargers for heavy commercial vehicles and expand the charging network at all levels, particularly in urban areas where off-street parking is common.
- **Incentivise EVs**: Create financial incentives for purchasing EVs or developing EV leasing schemes. For commercial vehicles ensure that there are cost parity schemes for road freight – either by making purchasing and operating diesel vehicles more expensive or helping EVs bridge the gap.
- **Fleet purchase mandates**: Implement mandates for public and corporate fleet purchases to include a minimum percentage of EVs.
- **Enhance consumer awareness**: Launch educational campaigns to inform consumers about the benefits and availability of EVs.

Municipalities and mayors:

- **Develop comprehensive clean and accessible mobility plans**: Implement mobility plans that expand clean public transportation, improve walking and cycling infrastructure to reduce congestion
- **Promote low-emission and zero-emission zones**: Restrict high-polluting vehicles (incl. heavier vehicles), invest in public transit and active mobility infrastructure, integrating digital monitoring systems to enforce compliance and optimise traffic flow
- **Increase parking fees**: Raise fees for polluting vehicles to encourage a shift to cleaner alternatives. Potentially raise fees for all vehicles to encourage modal shift towards cleaner alternatives.

OEMs & battery manufacturers:

- **Accelerate EV development**: Focus on smaller, cost-effective EVs to limit the need for critical minerals and reduce overall costs.
- **Reduce battery costs**: Decrease battery prices to make EVs more affordable and accessible.

113 IEA (2024), *Global EV Outlook 2024.*

114 The EU has for instance recently introduced the EU Emissions Trading System 2, an extension of the existing EU ETS to new sectors, including road transport.

Utilities and energy providers:

- **Expand renewable energy integration:** Ensure that the increase in EV charging demand is met with renewable energy sources.
- **Grid management solutions**: Invest in smart grid technology to handle the increased load from EVs and optimise energy distribution.

> **Ensure proper vehicle scrappage:** With the accelerated pace of fleet electrification, ensuring proper old ICE scrappage should also be a key priority for policymakers to prevent these polluting vehicles from ending up in second-hand markets.

Policymakers:

- **Develop scrappage schemes**: Introduce programmes to encourage the scrapping of old, polluting vehicles.
- **Enforce cross-country policies**: Prevent the transfer of old vehicles to second-hand markets to avoid prolonged fossil fuel use.
- **Environmental regulations**: Implement stringent environmental regulations on vehicle scrappage processes to ensure they are environmentally friendly.

Municipalities:

- **Implement emission zones**: Use low-emission and zero-emission zones to incentivise scrapping of old vehicles.

> **Process Energy Efficiency:** Energy efficiency improvements can be achieved with ambitious policies.

Policymakers and industry leaders:

- **Support research**: Invest in similar research groups to the China All-Solid-State Battery Collaborative Innovation Platform (Casip), uniting major battery manufacturers, automakers, academia and government to accelerate the research, development, and commercialisation of solid-state batteries and other battery chemistries.[115]
- **Encourage collaboration**: Foster partnerships between technology players (e.g., in-wheel motor manufacturers, battery developers, tyre companies, and car manufacturers).
- **Promote hybrid ICE development**: Support the development of hybrid ICEs without hindering fleet electrification.
- **Reduce speed limits**: Reduce speed limits by 20 km per h on highways (e.g., to 110 km per h) and to 30 km per h in urban areas.
- **Regulate vehicle attributes**: Introduce bans or taxation on excessively heavy vehicles and increase parking fees.
- **Set strong standards**: Enforce rigorous standards to encourage zero-emission transportation.

> **Service Efficiency Policies:** Service efficiency relies on systemic transformation and behavioural changes, requiring all stakeholders to work hand in hand.

Policymakers:

- **Urban mobility plans**: Develop and implement comprehensive urban mobility plans that prioritise sustainable transport modes.
- **Rail network investment**: Increase funding for rail infrastructure to enhance public transport options.

Municipalities and Mayors:

- **Promote cycling**: Invest in cycling lanes, e-bike subsidies and bike-sharing programs.
- **Support car-sharing**: Implement car-sharing lanes and subsidies.
- **Invest in public transport**: Expand bus lanes, subways, and tramways.
- **Alternate car days**: Introduce policies to reduce car usage on specific days.
- **Optimise traffic flow**: Implement measures to improve traffic management.
- **Pedestrian-friendly infrastructure**: Invest in pedestrian-friendly infrastructure to encourage walking and reduce reliance on cars.

Corporates:

- **Carpooling benefits**: Offer incentives for carpooling.
- **Encourage remote working**: Promote teleworking to reduce the need for commuting.
- **Fleet optimisation tools**: Use fleet optimisation tools to improve route planning and reduce fuel consumption for corporate fleets.

Consumers:

- **Adopt behavioural changes**: Shift towards sustainable transportation habits.

> **AVs:** Given the rebound effect associated with AVs, it is crucial for regulators and OEMs to prioritise their appropriate applications to ensure climate-positive impacts.

115 Electrive (2024), *China to pour millions into solid-state battery research.*

Policymakers:

- **Set early standards**: Establish regulations for AVs to prevent rebound effects, prioritising robo-shuttles and shared robo-taxis.
- **Data privacy regulations**: Establish robust data privacy regulations to protect users of AVs.

Commercial vehicle manufacturers:

- **Focus developments**: Focus development and investment efforts on autonomous technologies for commercial use and public transportation use.
- **Explore gains on driverless cabins:** Eliminate the need for driver cabins in AVs, increasing space for cargo and optimising logistics.

Tech companies:

- **Collaborate with automotive industry**: Partner with car manufacturers to integrate digital solutions into AV development early on.
- **Enhance software**: Improve energy consumption from embarked cloud computing, possibly through a more efficient network
- **Cybersecurity measures**: Invest in advanced cybersecurity measures to protect AV systems from hacking and other threats.

Cross-Cutting Measures: Other cross-cutting measures.

All stakeholders:

- **Encourage smaller vehicles**: Promote the use of smaller vehicles to optimise material requirements and increase the efficiency of battery use, as demonstrated in Exhibit 4.2.
- **Design for disassembly**: Encourage vehicle designs that facilitate easy disassembly and recycling of components, key to change batteries over time.

Acknowledgements

The team that developed this briefing comprised:

Lord Adair Turner (Chair), Faustine Delasalle (Vice-Chair), Ita Kettleborough (Director), Mike Hemsley (Deputy Director), Benjamin Neves, Stephannie Dittmar Lins and Elena Pravettoni (lead authors) and Andrea Bath (supporting lead author) with support from John Allen, Hannah Audino, Rose Dortch, Manuela Di Biase, Apoorva Hasija, Elizabeth Lam, Lina Morales, Niklas Niemann, Shane O'Connor, Phoebe O'Hara, Viktoriia Petriv, Caroline Randle, Sam Wilks (SYSTEMIQ).

The team would also like to thank the ETC members and experts for their active participation:

Nicola Davidson (ArcelorMittal); Alan Thomson and Julia Mills (Arup); James Butler (Ausgrid); Albert Cheung (BloombergNEF); Gareth Ramsay (bp); Sanna O'Connor-Morberg (Carbon Direct); Justin Bin LYU and Yi Zhou (CIKD); Adam Tomassi-Russell (Deep Science Ventures); Thomas Coulter and Annick Verschraeven (DP World); Adil Hanif, Rita Sa Couto and Tali Trigg (EBRD); Fu Sha (EF China); Cedar Zhai and George Wang (Envision); Keith Allott and Rebecca Collyer (European Climate Foundation); Eleonore Soubeyran (Grantham Institute, London School of Economics); Matt Prescott (Heathrow Airport); Kash Burchett and Sophie Lu (HSBC); Francisco Laveron, Isabel Gómez Bernal (Iberdrola); Yanan Fu (ICCSD); Chris Dodwell (Impax Asset Management); Andy Wiley (Just Climate); Ben Murphy (Kiko Ventures); Freya Burton (LanzaTech); John Bromley and Nick Stansbury (L&G); Kyllian Pather (Lombard Odier); Vincenzo Cao (LONGi); Abbie Badcock-Broe (National Grid); Rachel Fletcher (Octopus Energy); Rahim Mahmood and Amir Hon (Petronas); Leonardo Buizza (Quadrature Climate Foundation); Susan Hansen (Rabobank); Udit Mathur (ReNew); Greg Hopkins (RMI); Emmet Walsh (Rothschild); Emmanuel Normant (Saint Gobain); Vincent Petit (Schneider Electric); Anant Wadhwa, Brian Dean and Ben Hartley (SEforAll); Charlotte Brookes and Halla Al-Naijar (Shell plc); Jonny Clark (SLR Consulting); Martin Pei and Jesper Kansbod (SSAB); Alistair McGirr (SSE); Sharon Lo (Tara Climate Foundation); Abhishek Goyal (Tata Sons); Saurabh Kundu (Tata Steel); A K Saxena (TERI); Reid Detchon (United Nations Foundation); Mikael Nordlander (Vattenfall); Niklas Gustafsson, Staffan Rödjedal, Rolf Willkrans (Volvo); Molly Walton (We Mean Business Coalition); Jennifer Layke (World Resources Institute); Paul Ebert and Joachim Meister (Worley); Richard Hardy (X-Links).

The team would also like to thank the ETC's broader network of experts for their input:

Vincent Berger (DeepDrive); Aurélien Bigo (Chaire Energie et Prospérité); Georg Bieker, Jan Dornoff and Kyle Morrison (The International Council on Clean Transportation); Luke Osmokrovic (Oxa).

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