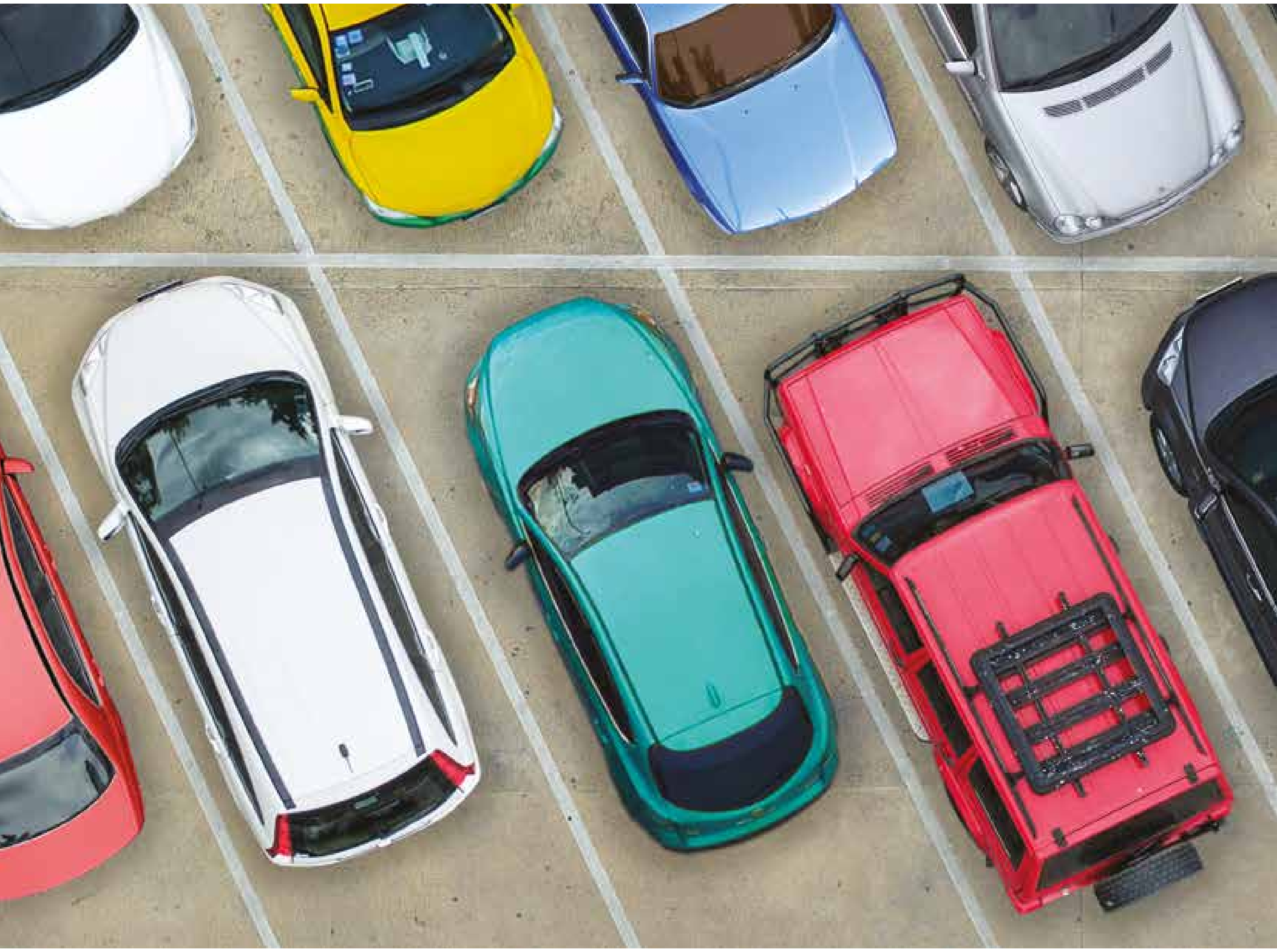
GLOBAL FUEL ECONOMY INITIATIVE
FOR ZERO CARBON VEHICLES BY 2050

TRENDS IN THE GLOBAL VEHICLE FLEET 2023

MANAGING THE SUV SHIFT AND THE EV TRANSITION



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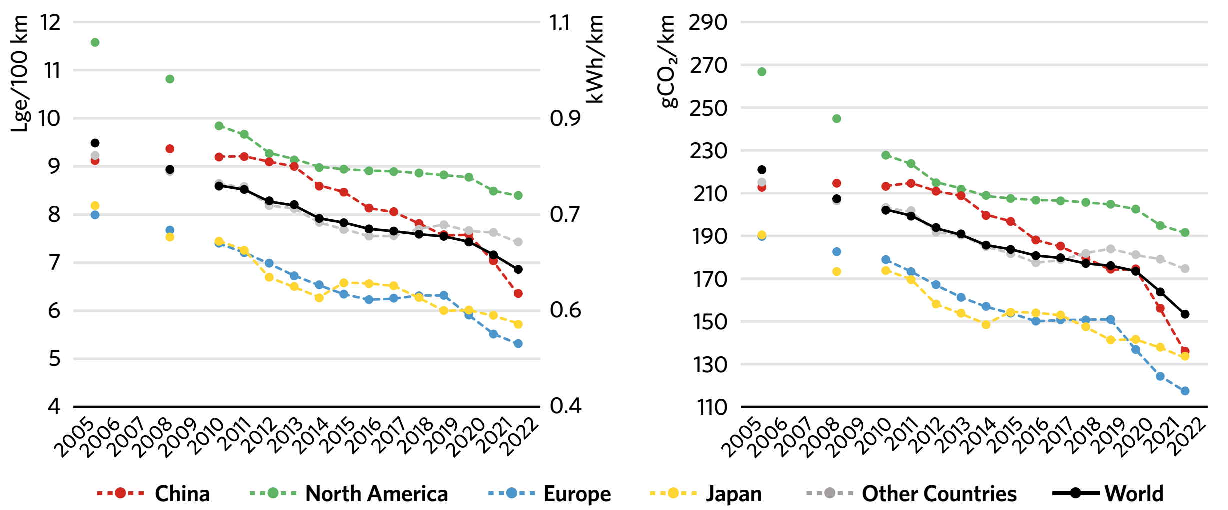
CONTENTS

EXECUTIVE SUMMARY

This is the latest update of a benchmarking report looking at the specific fuel consumption of light-duty vehicles (LDVs). While reporting data starting in 2005, it focuses on changes that occurred between 2019 and 2022.

Key developments include a 15% contraction of global LDV sales in 2020 as a consequence of the pandemic, and a limited recovery in sales through 2022. The sales-weighted specific energy consumption of LDVs decreased in all major car markets from 2019 to 2022, improving at an average yearly rate of 3.2% and reaching 6.9 Lge/100 km in 2022 (0.64 kWh/km). This is a doubling of the average improvement rate observed between 2005 and 2019 (1.6%) (Figure ES1). Direct CO_2 emissions have declined even faster, at a rate of 2.1% per year between 2005 and 2022, as electrification affects carbon emissions more than energy consumption.

FIGURE ES1: Trends in the specific energy consumption of new light duty vehicles in major markets



Notes: Lge stands for litres of gasoline equivalent, and it is used to standardise fuel consumption according to their volumetric energy content, like kWh/km. There are 9.3 kWh per Lge. Historical specific energy consumption values have been benchmarked according to new understanding of the ratio between NEDC and WLTP test cycle energy intensity and CO_2 emissions performance. This revision has improved the real-world representativeness of the reported specific energy consumption.

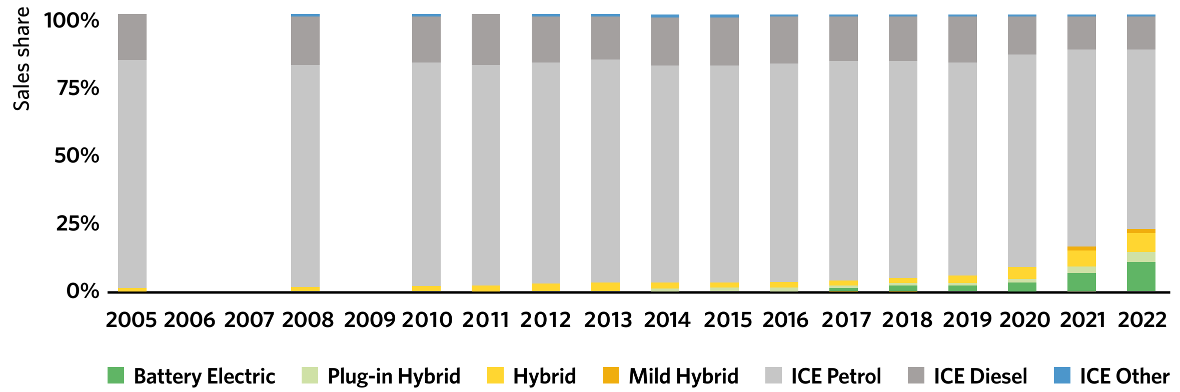
Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

The global average annual rate of energy intensity reductions in the period from 2020 to 2022 was 4.2%. If this rate of improvement could be sustained through 2030, it would bring LDVs very close to meeting the GFEI target of doubling the energy efficiency of new LDV sales by 2030 from a 2005 baseline.

The rapid acceleration in energy efficiency seen in recent years is mainly due to the uptake of electric light-duty vehicles (EVs, which include both battery electric vehicles [BEVs] and plug-in hybrids [PHEVs]) (Figure ES2). Electric powertrains consume three to six times less energy than internal combustion engine vehicles to cover a unit of distance and their sales share reached 15% in 2022. The yearly rate of energy efficiency improvement between 2019 and 2022 was more pronounced (close to 6%) in markets where EV sales increased the most, namely China and Europe. In North America, lower uptake of EVs and a continued trend in sales of larger and heavier vehicles has resulted in a yearly improvement rate of 1.6%. In countries where EVs are not widely deployed, annual improvement rates are also close to 1.5%.

The efficiency of new vehicles is also linked with the size, weight, and power of new cars. A long-term shift towards Sport Utility Vehicles (SUVs), underpinning increases in larger, heavier, and more powerful vehicles, has continued in major automotive markets and across nearly all countries (Figure ES3). In 2022, sales of SUVs overtook sales of conventional cars at a global level, reaching 51% of the total. Globally, the average vehicle weight of LDVs has also reached an all-time maximum, at 1530 kg. Average footprint has stagnated after 2019/2020 at about 4.2 m^2. Increases took place in low- and medium-income countries, typically starting from a lower baseline. Limited declines occurred mainly in China and Europe.

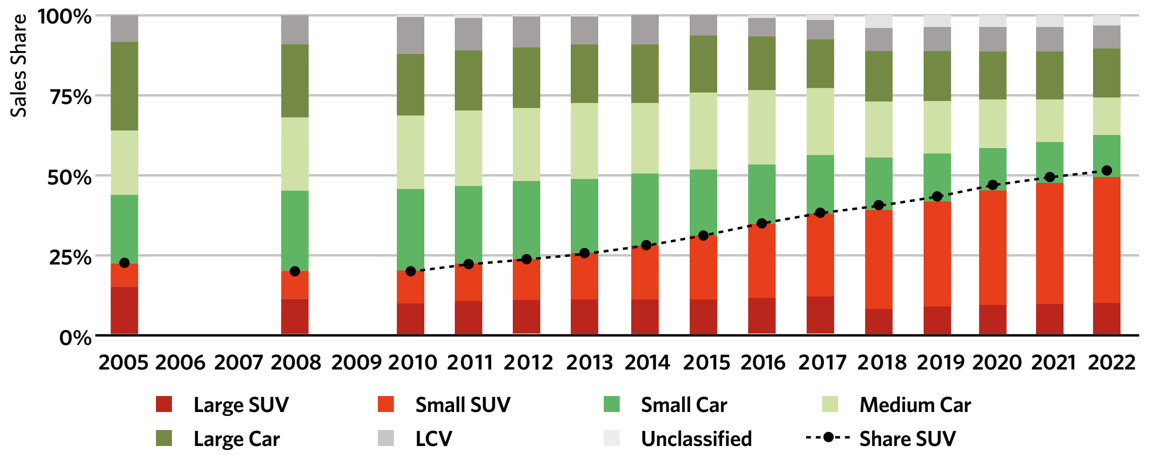
FIGURE ES2: Global LDV sales shares by powertrain



Note: ICE stands for internal combustion engine.

Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE ES3: Global LDV sales by segment



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

The two main trends underpinning developments in the global car market – a market shift towards SUVs and the transition toward EVs – have far-reaching implications for the automotive industry, as well as on the environment and society.

Shifts to larger and heavier vehicles led to increased oil consumption, direct CO_2 emissions and vehicle weight, size and power. Without the shift towards SUVs, energy use per km for combustion engine vehicles could have fallen at an average annual rate that is 30% higher than it did from 2010 to 2022. In the absence of the SUV shift, vehicle weight increases for these same vehicles could also have been more than halved.

Impacts of the SUV shift on energy use and direct emissions of CO_2 per km are being offset by increased electrification, thanks to markedly lower specific energy consumption versus combustion vehicles.

Electric vehicles however tend to weigh more than combustion vehicles, and their rise has added to the weight increases coming from the shift from small and medium cars to SUVs.

Despite increases in disposable income of households worldwide, the SUV shift was instrumental for an increase in original equipment manufacturers (OEM) profitability that remained in place even after the contraction observed in the global LDV market. This, however, also resulted in relevant affordability and equity challenges within and across countries. Higher investment costs needed for EVs exacerbated these challenges, even if savings from lower energy and maintenance costs for EVs help to mitigate this effect on a total cost of ownership basis.

Legacy OEMs have been slow to enter the EV market, especially in smaller segments, despite the risk of exposure to long-term losses of market shares to Chinese competitors. Reasons include the near-term focus on higher profitability, the cost of the batteries for BEVs and complex powertrains for PHEVs, challenges in the development of new battery supply chains and large capital outlays for investment in new industrial facilities.

Equity-related challenges and greater exposure of low-income households and businesses to the combined market transformation towards EVs and SUVs point towards the possibility of a growing global divide, not only within different income groups within countries, but also between major developed economies and other countries.

POLICY OPTIONS

Managing these developments requires a broad range of policy actions.

- The adoption and continued development of fundamental pre-requisites: technical standards, increased low-carbon electricity availability, and removal of fossil fuel subsidies.

- A coherent policy framework is also needed beyond tailpipe emissions, taking a holistic approach to address impacts of LDV production and operations from a lifecycle perspective.

Novel regulatory mechanisms can address issues related to increased vehicle size and weight.

- The introduction of a cap on vehicle footprint, in absolute terms and as a sales-weighted average, paired with net declines going forward, to limit and then reverse the SUV shift.

- Corporate-average regulatory requirements, similar to those in place for fuel economy or CO_2 emissions, having battery capacity (kWh/vehicle) as the regulated parameter. These could be especially effective to complement the footprint regulations to reverse the SUV shift, addressing critical mineral issues from the demand side and equity issues specifically related with EVs through product diversification, while leaving room for innovation in battery chemistries and providing flexibility in compliance strategies for automakers.

- The use of vehicle footprint, rather than weight, is also suggested as the best choice as a modulating parameter in existing regulations on specific energy consumption or direct CO_2 emissions, alongside tightened requirements for larger vehicles (including both ICEVs and EVs). This is because regulating based on footprint can incentivize lightweighting as an energy consumption reduction strategy, whereas weight-based regulations fail to do this.

This report proposes also to target more stringent environmental and safety regulations on highly utilized vehicles such as company cars, taxis, government fleets, and ride- and carsharing services. Measures requiring higher EV market shares and incentivizing electric vkm in these use cases can enhance efficiency in the use of minerals for EV batteries and may also generate positive spillovers in terms of equity.

Adapting existing policy and regulatory instruments can also help address these issues.

- Vehicle taxation reforms – including the integration of weight and prices as modulating parameters for vehicles taxes and charges, at the national and at the local levels – can help steer vehicle markets away from SUVs and encourage EV adoption without reducing government budgets.

- Fossil fuel taxes and carbon pricing mechanisms offer important opportunities to provide economic incentives for EVs. Incentives need to be targeted on more vulnerable households and businesses, facilitating a more equitable and inclusive transition. They can be financed from revenues from fossil fuel taxes and carbon pricing.

- Regulatory and fiscal measures supporting universal access to EV charging infrastructure are needed to enable consumers to gain more confidence to undertake a larger share of their trips even with a shorter range, thereby also addressing weight-related challenges for EVs.

- Sustainable finance frameworks, important to help achieve a better alignment between the decisions taken by investors, corporations and other entities, can benefit from updates in their taxonomies regarding weight-related attributes of vehicles.

- Financial instruments designed to facilitate access to EVs for capital-constrained households and small businesses, as well as initiatives favouring access to capital at lower cost, are crucial to help favouring an equitable transition, domestically and internationally.

While it is also technically feasible to make progress by reforming trade rules and tariffs applied to critical minerals, EV battery, and vehicles, progress on this depends upon the effectiveness of the dialogue and negotiations taking place at the intergovernmental level. Possible improvements to trade-related policies on vehicles include differentiated tariffs based on powertrain, battery size, energy efficiency, GHG emissions, vehicle weight and footprint. They are feasible as long as the differentiation aligns with rules of origin, environment- and national security-related exceptions foreseen by the World Trade Organization (WTO).

1 INTRODUCTION

This report is the latest update and sixth instalment of the Global Fuel Economy Initiative's biannual benchmarking report on light-duty vehicle sales, extending the analysis from 2019 through 2022. Previous reports tracked the technical, market, and policy drivers of fuel economy and CO_2 emissions performance of new light-duty vehicles (LDVs) at a country, regional, and global level (Cuenot and Fulton, 2011, Cuenot and Körner, 2013, IEA, 2019a, and IEA, 2021a). These reports, together with other GFEI analyses (Cuenot, 2017), have documented the rising market shares of Sport Utility Vehicles (SUVs), and more generally, of larger and heavier vehicles, and analysed the impact of these trends on energy efficiency and CO_2 emissions in major LDV markets.

This report tracks this continuing trend, highlighting key implications, including reduced energy and resource efficiency, increased vehicle production costs and reduced affordability for vehicle owners – exacerbating inequalities within and among countries – as well as heightened injury and mortality risks to pedestrians, cyclists, and car drivers alike. Examining vehicle sales trends in low- and medium-income countries, this work also extends themes developed in the UC Davis report commissioned by the FIA Foundation for the ZEV Transition Council, "Facilitating a Transition to Zero-Emission Vehicles in the Global South" (Cazzola and Santos Alfageme, 2023).

Chapter 2 illustrates that the tendency towards larger market shares for vehicles in larger heavier vehicle segments is persistent and widespread. The same analysis also shows a rapid increase in vehicle electrification, with strong EV adoption in China, Europe, Korea, Japan and North America,[1] resulting in substantial energy intensity and GHG emission reductions.

Chapter 3 analyses key determinants of the observed market developments, with a specific focus on the shift towards SUVs and the increase in EV shares. It examines the broader impacts of these dynamics, focusing on vehicle size, weight, and price increases, and considers aspects related with energy, emissions of CO_2 and local air pollutants, road safety, demand for minerals resources, and equity.

The following analysis, in Chapter 4, reviews policies already developed by governments to address the impacts of recent market developments, identifies best practices, and recommends changes and new regulatory instruments that are best suited to address the challenges discussed in Chapter 3, placing a greater emphasis on solutions that help bridge the risk of a global divide.

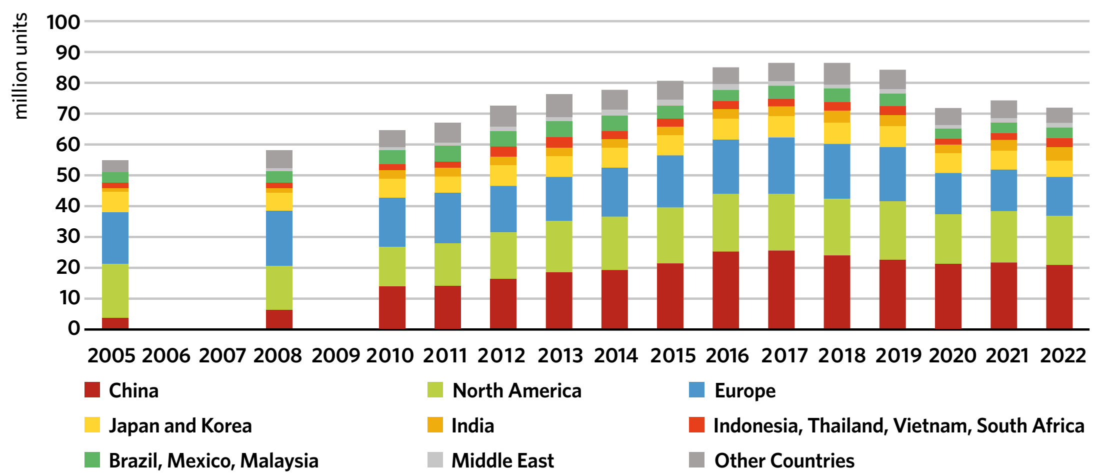
The methodological approach of this update differs from previous GFEI benchmarking reports. Rather than relying on a database with detailed model-level and in some cases trim-level data and including an extensive list of vehicle technical parameters (e.g., weight, footprint, engine capacity, number of doors, presence of efficiency technologies such as continuously variable transmissions, turbochargers, etc.), this data update relies on lower resolution data (still at the model level) from Marklines. The Methodological Annex outlines the methods used to ensure as close as possible consistency with previous reports, and to verify the accuracy and validity of this assessment.

2 KEY DEVELOPMENTS IN LIGHT DUTY VEHICLE MARKETS

2.1 NEW SALES OF PASSENGER CARS AND LIGHT COMMERCIAL VEHICLES

Worldwide, the sales of light-duty vehicles (LDVs) – including passenger cars and light commercial vehicles[2] – steadily increased through 2017, and then slowed down through 2019 (Figure 1). Long term-trends were disrupted by the Covid-19 pandemic in 2020, which resulted in a rapid drop of sales across all regions: globally, 15% fewer LDVs were sold in 2020 than in 2019. Following 2020, sales rebounded, but are still around 10% lower than they were before the pandemic.

FIGURE 1: Global LDV sales by region 2005-2022



Note: LDV sales included in this analysis and in this graph are those for the countries listed in annex Table A6. Europe includes all member countries of the European Economic Area (EEA) plus Switzerland and the United Kingdom. North America includes the United States and Canada but excludes Mexico, included in the same group as Brazil and Malaysia, as they have similar characteristics with respect to GDP per capita, while still having a comparable population density, the presence of an automotive manufacturing capacity and not being a net importer of oil and petroleum products. Total sales for this set of countries are equivalent to roughly 85% of the total vehicle sales accounted by OICA – including commercial vehicles (OICA, 2023), meaning that they represent the vast majority of light duty vehicle sales globally.

Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

The rebound in sales has been slowed down by a stretched supply chain – especially due to a shortage of microchips – that has struggled to keep up with swings in demand (JP Morgan, 2023; Brinley, 2023, Straughan, 2023; Burkacky et al., 2021; Burkacky et al., 2022). Shifts in the market structure, as discussed below, accompanied by changes in vehicle prices as larger vehicles are above those of smaller ones, discussed in Chapter 3, are also influencing consumer choices regarding the acquisition of a new vehicle, including through postponement of purchases (GfK, 2023; Shmuel, 2022; Romei, 2022) or an increased consideration of second-hand options, where they are available (Roch Baranowski et al., 2023; Manheim, 2023).

The Chinese LDV market has undergone a very rapid rise since the beginning of the century. China became the world's largest LDV market in 2009 and from 2020 through 2022, with annual sales of 21 million vehicles, it has become by far and away the world's largest automotive market, accounting for 29% of global LDV sales in 2022. All the same, China's sales peaked in 2017 and have since been slowly declining. Several factors, often limiting growth in car ownership, help explain why the stabilization of car sales occurred when the number of cars per capita in China is still well below the levels observed in economies with higher per capita income. These reasons include, in addition to recent supply-chain challenges:

- the early phase of a transition from a growth market where most vehicles were sold to first-time owners to a mature "replacement" market;
- significant investments in public transport, including urban and intercity rail services (Xinhua, 2020; IEA, 2019b; and Ou et al., 2022);
- the frequent use of policies managing access to personal vehicles in cities, also in light of the transition to vehicle electrification (Feiqi et al., 2020; Liu et al., 2022; Jin et al., 2023; and He et al., 2018); and
- a pro-active deployment of digitally-enabled shared mobility services (Yin et al., 2022).[3]

The 2020 pandemic also had a much smaller impact in the Chinese market than in all other markets, with sales only declining around 5% year on year. Sales in China have subsequently remained fairly constant.

Sales in mature markets such as North America, Korea, Japan and Europe[4] remained mostly stagnant through 2019. With sales increasing in China by nearly seven-fold in 2020, relative to 2005 (and despite the decrease in sales from 2017 onwards) and with other countries, such as India, Indonesia, and Brazil, the combined share of these mature markets out of the global market has declined from over 70% in 2005 to under 50% in 2022.

LDV sales in North America declined 14% in 2020 from their 2019 level, and have dropped a further 5% since then, to 13.9 million vehicles in 2022. Global supply chain constraints and rapid inflation, with the prices of new cars and trucks rising even higher than other consumer goods (Bureau of Labor Statistics, 2023), justify this reduction.[5]

In Japan, sales of LDVs declined by more than 10% since the pandemic and remained roughly constant thereafter.

In Korea the pandemic did not lead to any reduction in sales, but there has been a small decline since 2020. In 2022, Korea and Japan accounted for 8% of global LDV sales, the same share they accounted for pre-pandemic.

The European market has been slower than others to recover from the impacts of the pandemic due to regional shortages of vehicle components that were aggravated by Russia's invasion of Ukraine (VDA, 2022). This has led Europe's share of the global market to decline from 21% in 2019 to 18% in 2022.

Vehicle sales in emerging markets such as India, Indonesia, and Brazil grew substantially between 2005 and 2010, but their growth has slowed down since. In 2022, these markets accounted for 22% of global sales. The pandemic and the ensuing economic difficulties have also taken a toll on car sales in these countries, with a decline of 20% in 2020. Sales have since regained 7%, but they are still below pre-pandemic levels. Among these markets, the Indian market has been particularly dynamic, as it declined by a staggering 30% in 2020 but has since regained all the losses and sales volumes in 2022 exceeding pre-pandemic levels.

2.2 ENERGY EFFICIENCY OF NEW VEHICLES

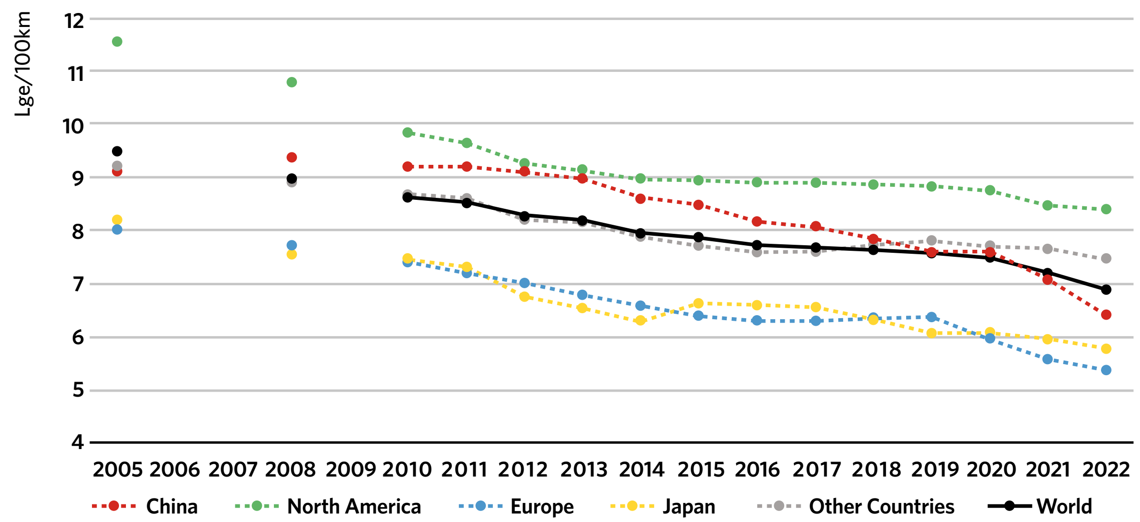
The specific energy consumption of new vehicles has decreased since the beginning of this benchmarking exercise. The global sales-weighted average fuel consumption for LDVs sold in 2022 was 6.9 Lge/100km (0.64 kWh/km)[6], nearly 30% less energy than the value in 2005. In 2020, GFEI partners reaffirmed their target to double the energy efficiency of new LDV sales by 2030 from a 2005 baseline. If it can be sustained through 2030, the global average annual rate of energy intensity reduction in the period from 2020 to 2022 (4.2%) would bring LDVs very close to meeting the GFEI target.

Worldwide, the pace of annual reduction in energy consumption per km declined over the 2010s, but marked improvements can be seen from 2019 onwards, as sales shares of electric vehicles have begun to ramp up substantially (Figure 2). The rapid acceleration in energy efficiency improvements seen in recent years is mainly due to the uptake of EVs, which include both BEVs and PHEVs, reflecting the fact that electric powertrains consume three to six times less energy to cover a unit of distance in comparison with powertrains reliant on internal combustion engines (ICEs) and their sales share reached 15% in 2022.

The yearly rate of energy efficiency improvement between 2019 and 2022 was more pronounced in markets where EV sales increased the most, namely China (5.9%) and Europe (5.8%). In North America, lower uptake of EVs and a continued trend in sales of larger and heavier vehicles has resulted in a yearly improvement rate of 1.6%. In countries where EVs are not widely deployed, annual improvement rates are close to 1.5%.

Fuel prices and income levels remain key determinants of vehicle energy use per km, leading to systemic differences across national and regional markets, as already identified in earlier analyses (IEA, 2019a, IEA, 2021a) and shown in Figure 3. The Figure shows specific energy consumption plotted against gasoline prices and GDP per capita, both corrected based on purchasing power parities. Results show that higher fuel prices (and taxes)[7] tend to be paired with lower energy consumption per km and also that specific energy consumption is higher in countries with lower levels of fuel taxation, across different levels of average income.[8]

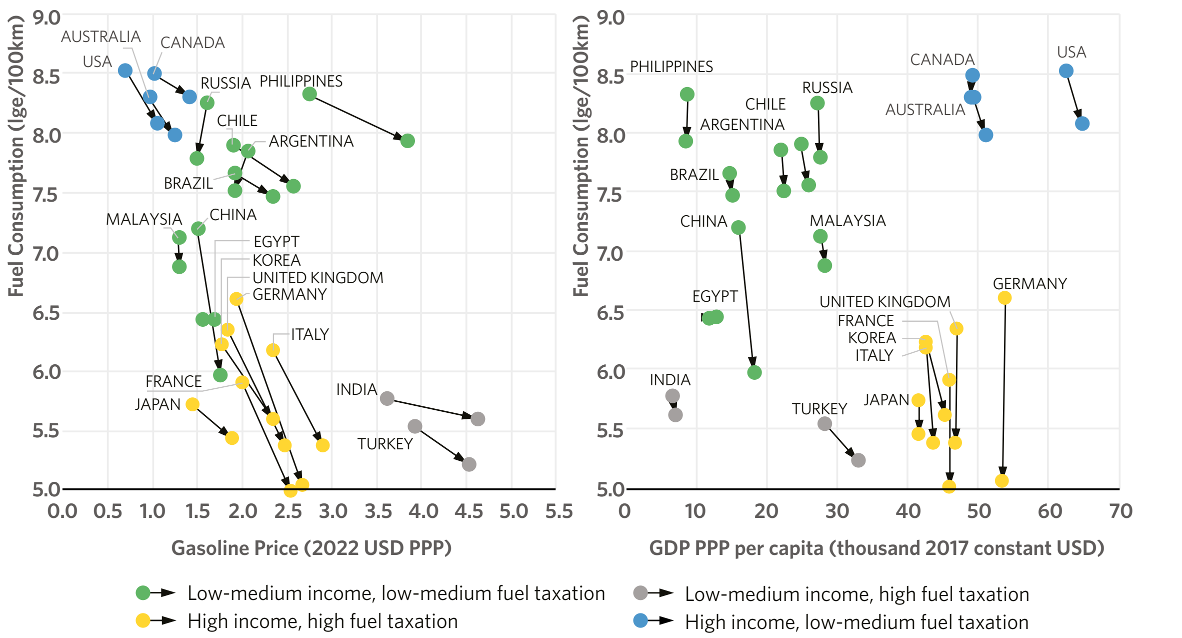
FIGURE 2: Trends in the specific energy consumption of new vehicles in major car markets



Notes: Data from 2005 to 2017 is based on Fuel Economy in Major Car Markets 2005-2017 (IEA, 2019a), while from 2019 onwards data follows the new methodology outlined in the annex. The year 2018 is shown as the average in values between 2017 and 2019.

Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE 3: Evolution of specific energy consumption and gasoline price (left) and GDP per capita (right), using purchasing power parities, 2019-2022



Notes: Arrows show the change from 2019 to 2022.

Sources: Specific energy consumption from this data assessment (see the Annex for sources and methods)
Gasoline prices from the IEA energy prices database (IEA, 2023a) GDP per capita PPP and PPP conversions are from the World Bank Open Data (World Bank, 2023).

The trends in the specific energy consumption of new vehicles shown in Figure 2 can be analysed looking at three phases. The first spans the years between 2005 and 2017, the second runs from 2017 to 2020 and the third (also having important implications for Figure 3) follows the year 2020. Figure 4 summarizes key developments characterizing each of these phases, considering the development of key driving factors and their evolution over the years.

Between 2005 and 2017, average fuel consumption declined at a yearly rate of 1.8%, with most improvements having occurred in the earlier part of this period. These improvements were driven by regulations in major car markets aiming to reduce fuel consumption and CO_2 emissions, setting the pace of technology deployment in a way that also influenced other markets. Carmakers largely delivered these improvements through improved internal combustion engine (ICE) and vehicle technologies. These included turbochargers and improved transmissions, engine downsizing, material substitution and light-weighting technologies, an increased use of diesel powertrains (especially in Europe, India and Korea) and hybrid powertrains (IEA, 2019a).

Between 2017 and 2020, improvements in rated specific energy intensity have mostly stagnated at a global level, with average specific energy consumption hovering 7.5 Lge/100 km (0.7 kWh/km). This period of stagnating improvements can be largely explained by two counteracting drivers.

- On the one hand, new vehicles became larger, heavier, and more powerful, with a shift in market segments (the SUV share increased from 38% to 46%) driving fuel consumption upward.

- On the other hand, the beginning of growing market shares of electric vehicles (EVs), substantially lowering sales-weighted average fuel consumption and tailpipe emissions.

Electric vehicle sales increased from 1.5% in 2017 to 4% in 2020, on the back of supportive government policies and market- and technology-driven cost declines (IEA, 2018; 2019b; 2020).

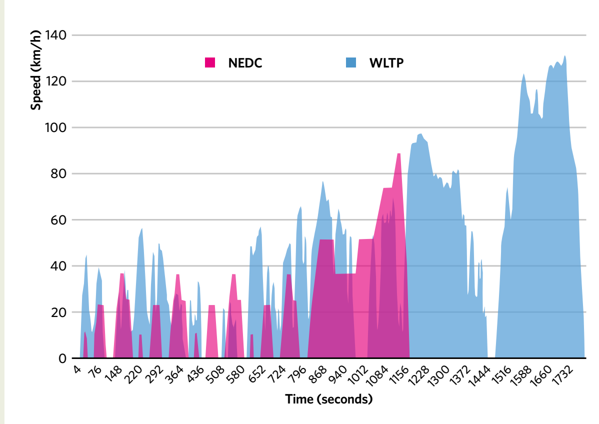
BOX 1:

REVISED BENCHMARKING OF NEDC TO WLTC CONVERSION

To enable global comparisons across countries and major markets, fuel consumption and CO_2 emissions data are converted from regional or national test cycles to a single globally harmonized test cycle, the Worldwide harmonized Light-duty Test Cycle (WLTC).

In earlier reports (from 2016 to 2021), conversion factors were taken from powertrain-specific (i.e. gasoline and diesel ICE) zero intercept regressions developed by the ICCT (Kühlwein et al., 2014).[10] This approach is revised here, using regressions based on actual type approval data providing CO_2 emissions based on both the NEDC and WLTC test cycles, as reported by the European Environmental Agency (EEA) for light-duty vehicles registered across Europe between 2019 and 2022.[11] This led to a revision of the gap between NEDC and WLTC, meaning that it is now larger than it had been initially assessed in 2014, in line with other literature (Pavlovic et al, 2018, JRC, 2023).

Table 1 highlights the main differences in the assessment of specific fuel consumption due to this update. These results, based on EEA data and compared with those of the 2014 assessment (Kühlwein et al., 2014), indicate that the earlier NEDC to WLTC conversion factors were lower by a factor of 1.05 for gasoline- and 1.20 for diesel-powered LDVs, in comparison with updated values.



As inter-cycle conversion factors for test cycles used in different regions (e.g., between CAFE and JC08 and NEDC) assessed in 2014 remain accurate, the factors summarized in Table 1 have been used to rebase results assessed in earlier editions of this work, while maintaining inter-cycle conversion factors unchanged.

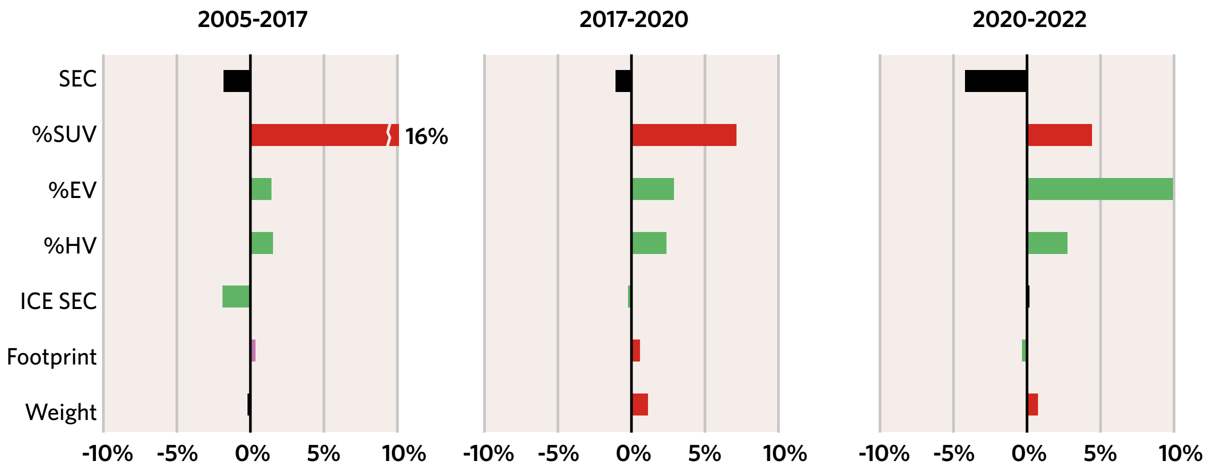
It is also worth highlighting that a gap remains between the WLTC factors and real-world fuel consumption, as has been established by a number of recent assessments (Tietge at al., 2017; Craglia and Cullen, 2019; IEA, 2019a; Dornoff et al., 2020; Komnos et al., 2022).

TABLE 1: Regression results for gasoline and diesel conversion between NEDC and WTLC

Powertrain	NEDC to WLTC ratio ICCT 2014	NEDC to WLTC ratio update EEA data 2019-22	Ratio between 2014 and updated factor
Gasoline	1.128	1.185*	1.05
Diesel	1.029	1.235*	1.20

* The values reported here are for the ratio between NEDC and WLTC emissions performance (g CO_2/km) for passenger cars. These ratios were determined also separately for passenger vehicles and light commercial vehicles for all basic powertrain-fuel combinations in the EEA dataset (gasoline, diesel, natural gas, LPG, gasoline-electric, diesel-electric, e85). Since direct CO_2 emissions for battery-electric and fuel-cell electric vehicles are 0 g CO_2/km, ratios for specific energy consumption are unaffected for these powertrains. Full regression results are provided in the Appendix.

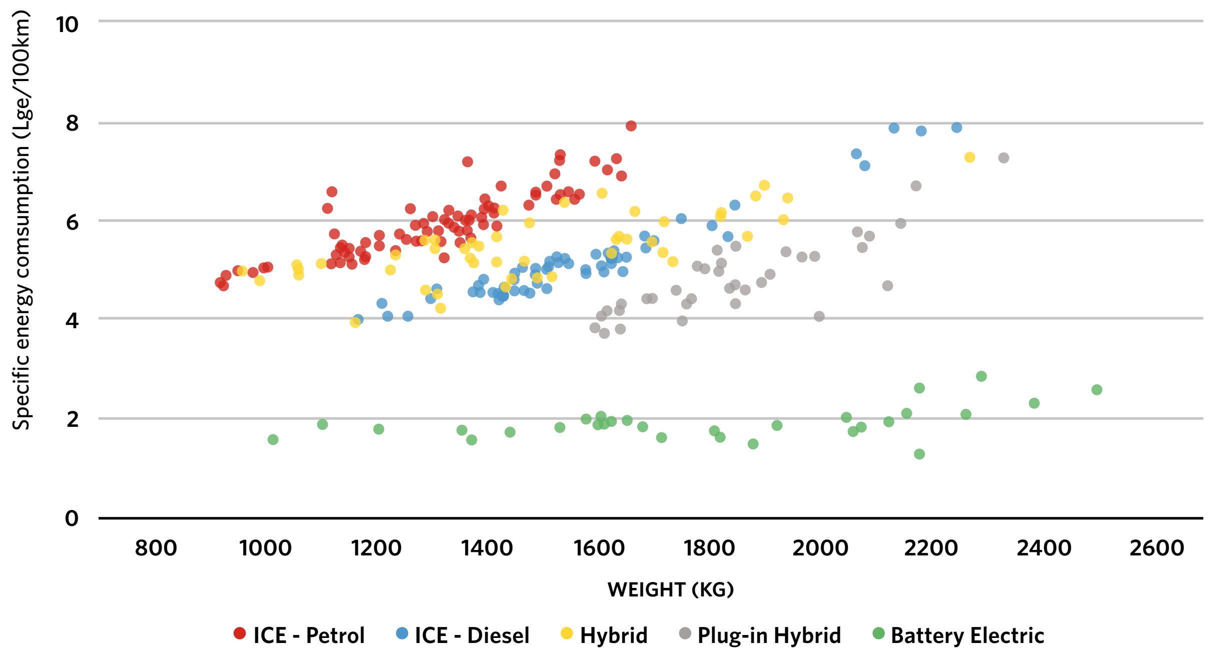
FIGURE 4: Changes in LDV specific fuel consumption and its principal drivers



Notes: SEC stands for specific energy consumption, calculated as the compound annual rate of increase/decrease.
ICE SEC stands for the specific energy consumption of ICE vehicles, calculated as compound annual rate of change. Footprint stands for the average vehicle footprint, calculated as compound annual rate of change. Weight stands for the average vehicle mass, calculated as compound annual rate of change. % EV refers to the change in the market share of electric vehicles over the period. % HV refers to the change in the market share of hybrid vehicles over the period. % SUV refers to the change in the market share of SUVs over the period. Green indicates a contribution that decreases specific energy consumption. Red indicates a contribution that increases specific energy consumption.

Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE 5: Specific energy consumption plotted against vehicle mass, by powertrain, for top selling light-duty vehicles in Europe



Source: based on 2021 European registration data from EEA, 2023a; EEA, 2023b. Specific energy consumption for PHEVs was calcuated using a utility factor derived from the all-electric range reported in the EEA database using a function reflective of real-world usage (Fraunhofer ISI, 2021), specific energy consumption of electricity for driving phased in all-electric mode and specific fuel consumption for other driving phases.

Between 2020 and 2022, the global average of the specific energy consumption of new vehicle sales decreased 8%. This equates roughly to a 4.2% year-on-year decrease, double what has been observed in any year previously over the entire GFEI database period that started in 2005 (as covered by this series of benchmarking reports). This suggests that, starting in 2020, trends in specific energy consumption have entered a new period, heavily influenced by the rise of EV market shares across all major LDV markets.

Indeed, China saw EV sales share start to grow very rapidly in 2019. Europe followed in 2020. Since 2022, a remarkable growth is starting to occur also in North America. With EV sales accounting for 15% of the global market in 2022, and limited changes in the energy use per km of new ICEVs, the impact of EVs on the specific energy consumption of light-duty vehicles is now significant, even at the global scale.

The surge in EV market shares that occurred after 2020 is paired with stronger changes in the patterns show in Figure 3, since markets with high increases in EV sales shares are those characterized by the most relevant drops in the specific fuel consumption of new vehicles. The cases of European countries and China are particularly visible, as they have undergone the fastest change. In China, the change was so pronounced that it now fits well within the cluster of developed countries with high fuel prices, while still having a relatively low level for fuel taxation.

2.2.1 TECHNICAL DETERMINANTS OF THE ENERGY EFFICIENCY OF VEHICLES

The specific energy consumption of vehicles depends primarily on two physical characteristics: it is proportional to the weight and size of the vehicle, and it is inversely proportional to the efficiency of the powertrain.

Figure 5 shows results relative to vehicles sold in 2022 in the European market and reflects differences taking place across both weight and powertrains.

Weight-related trends by powertrain show that heavier vehicles (which are generally also larger, and tend to be Sport Utility Vehicles, or SUVs) require more motive energy per unit distance. For example, a large SUV (such as a Ford F150) powered by a gasoline engine consumes around 11 Lge/100 km (1 kWh/km), while a medium car (such as a VW Golf) consumes 6.4 Lge/100km (0.6 kWh/km). Conversely, powertrains that more efficiently convert input energy into motion consume less energy to drive the same distance.

Differences in specific energy consumption across powertrains reflect differences in the capacity of different powertrains to convert energy into motion (IEA, 2021a).

- Gasoline-powered ICEs convert roughly 20%-25% of the energy available in the fuel into motion.
- Diesel powertrains are generally more energy efficient than gasoline ICEs with similar performance, requiring roughly 15% to 20% less energy than gasoline ICEs to perform the same service, despite a weight penalty.
- Hybrid vehicles convert around 35% of the fuel's energy into motion, cutting liquid fuel requirements by roughly 20% vs. ICE powertrains, thanks to the use of electric propulsion in driving phases where the ICE is particularly inefficient, which more than offsets higher energy demand (to recharge the batteries) in driving conditions with better ICE energy efficiency.
- Battery electric vehicles (BEVs) convert around 75% of the energy they receive into motion.
- Plug-in hybrids combine the benefits of BEVs and hybrids in a way that depends on the extent to which they are driven in charge-depleting mode (in which case their energy efficiency performance is close to a BEVs) or in charge-sustaining mode (in which case they behave in a way that is similar to a conventional hybrid vehicle).

Hybrids, plug-in hybrids, and battery electric vehicles also recover, with limited losses, the kinetic energy of vehicles during braking, with larger energy efficiency advantages vs. ICEs for heavier vehicles. Further variability depends on driving speeds and the use of auxiliaries (e.g., air conditioning).[9]

2.2.2 TAILPIPE CO_2 EMISSIONS OF NEW LIGHT DUTY VEHICLES

The tailpipe carbon dioxide emissions from new sales have evolved in a very similar way to the specific energy consumption, as shown in Figure 6. The two quantities are proportional and closely related.

For vehicles powered by fossil fuels, declines in tailpipe CO_2 emissions are directly proportional to the declines in specific energy consumption. The key difference in trends between the two parameters is driven by the presence of EVs, and in particular of BEVs: their specific energy consumption is around 70% lower than that of ICEs, while their CO_2 emissions are 100% lower, as they emit no CO_2 tailpipe emissions.

Until 2019, 95% of all vehicles sold globally were powered by traditional internal combustion engine powertrains. A major driver for improvements in fuel economy through 2019 was the introduction, growth, and eventual decline of diesel powertrains in Europe and India.

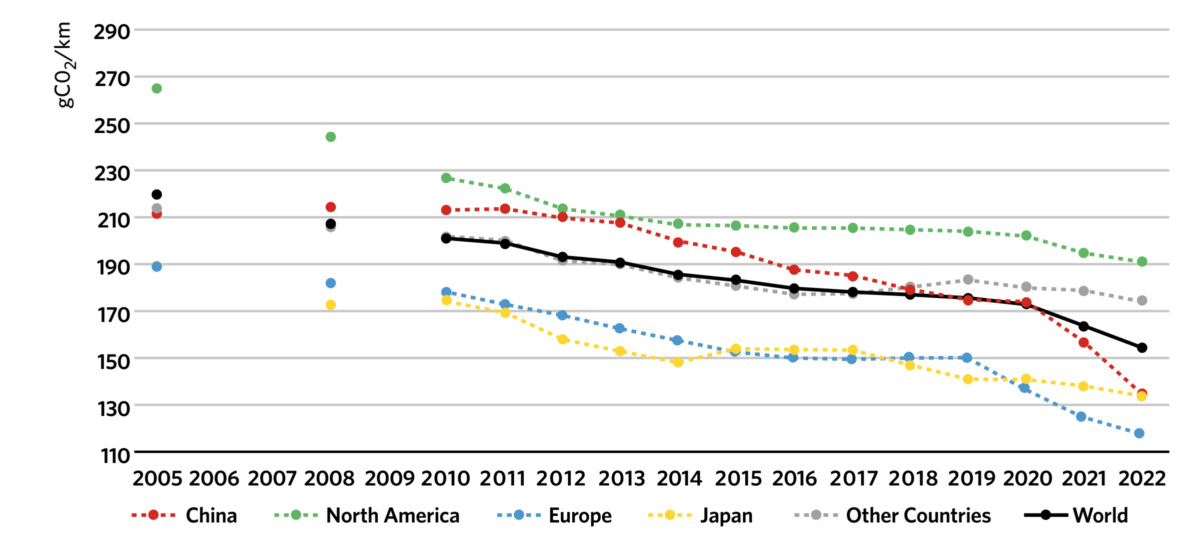
This means that the electrification trend is stronger than the SUVs shift, when looking at this parameter. Therefore, unlike specific energy consumption, CO_2 emissions have continuously declined at a global level. The decline was 1.6%, on average, per year, from 2005-2019, and 4.6% between 2019 and 2022 – faster than the decline in specific energy consumption. Similarly, we observe that all markets where electrification has advanced CO_2 emissions have declined faster than specific energy consumption.

2.3 VEHICLE SALES BY POWERTRAIN

Figure 7 summarizes the dynamics the LDV market has evolved in terms of vehicle powertrains. It considers both global developments (across the whole period analysed here) and specific cases, represented by selected years and targeted markets.

Until 2019, 95% of all vehicles sold globally were powered by traditional internal combustion engine powertrains. A major driver for improvements in fuel economy through 2019 was the introduction, growth and eventual decline of diesel powertrains in Europe and India. Diesel engines proved to be a good solution to reduce CO_2 emissions, but improvements came at the expense of increased air pollutant emissions.[12] The discovery of these increased emissions in 2015 has marked the beginning of the decline for this powertrain in both Europe and India. In 2022, diesel powertrains accounted for 23% of sales in Europe and 25% in India.

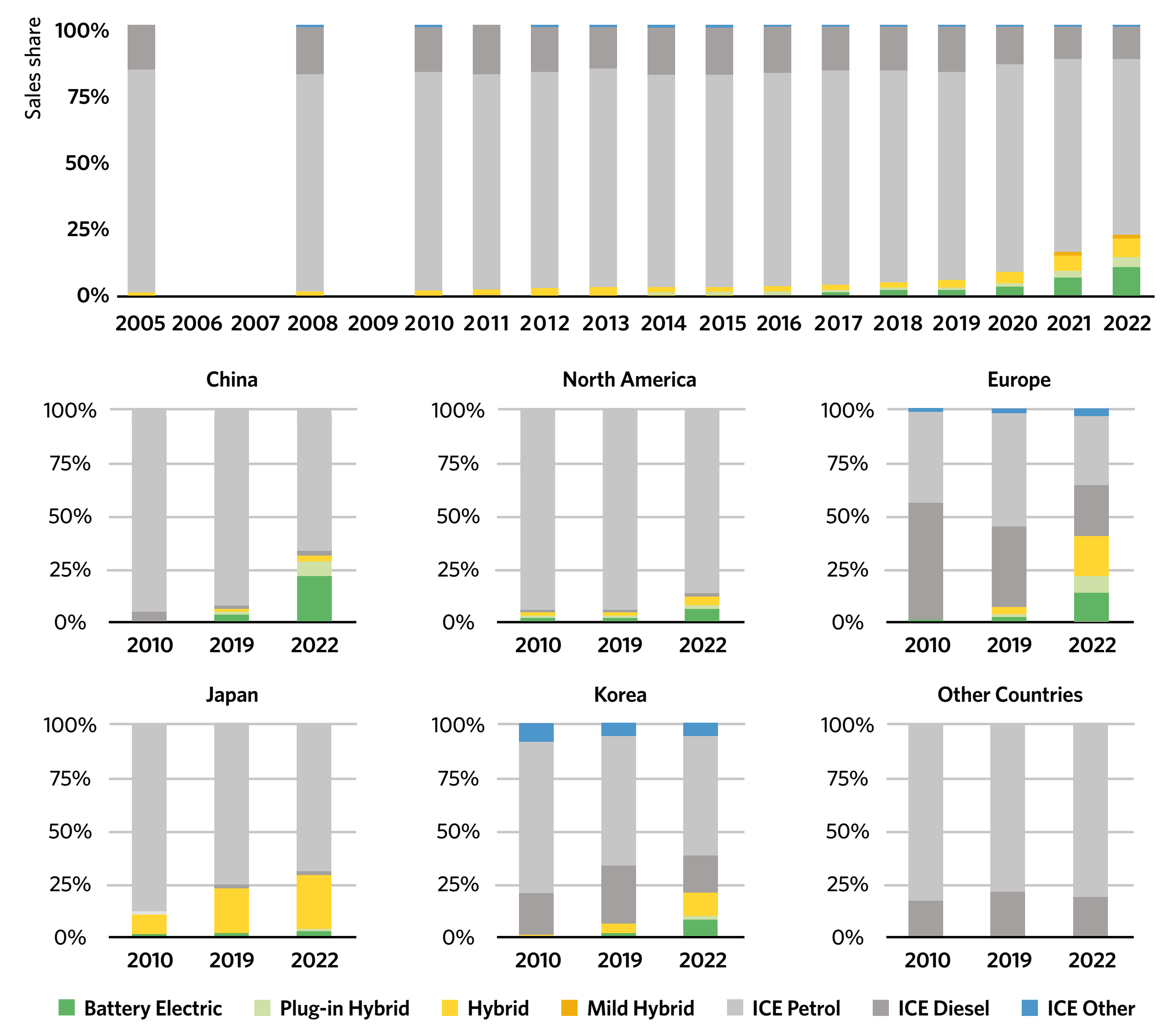
FIGURE 6: Trends in the tailpipe CO_2 emissions of new vehicles in major car markets



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

As shown in Figure 5, hybrid vehicles offer energy savings relative to gasoline-fuelled vehicles. They also offer reduced air pollutant emissions relative to diesel-fuelled vehicles. This technology was pioneered in Japan, where hybrid vehicles account now for about one-quarter of sales. Worldwide, hybrid sales shares remained constant from 2013 to 2019, accounting for roughly 3% of all vehicles entering the market. Over this period, relatively low oil prices and limited availability of hybrid models have limited market penetration, mostly to Japan and Korea, where hybrid sales shares reached 20% and 6% of the total, respectively, in 2019. Since then, hybrid sales have further increased in Korea, reaching a 12% market share in 2022. From 2019 onwards, hybrids have also made inroads in the European market, mostly driven by regulatory pressures to reduce fuel consumption and reflecting increased model availability. Hybrid sales increased in Europe from 4% in 2019 to 19% in 2022. Hybrids also grew in market relevance in North America, with sales shares reaching 5% in 2022. Despite a growing trend, hybrid vehicles have small market share in China, reflecting a strong policy focus on BEVs.

FIGURE 7: LDV sales shares by powertrain: global and in selected markets



Notes: ICE stands for internal combustion engine – Other includes compressed natural gas (CNG) and liquefied petroleum gases (LPG) powered vehicles.

Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

PHEVs and BEVs, accounted for limited shares at the global level until 2016, at which point sales surpassed two million units (IEA, 2017). By 2019, EVs reached 2% of global sales. Norway was an early adopter, with shares well above global average already before 2019. By 2019, EV sales accounted for 56% of the market in Norway, more than ten times the 5% share of China and the 3.5% share for the European market as a whole (IEA, 2020 and this assessment). EV sales shares increased sharply in 2020 in Europe, with OEMs selling more EVs to comply with the more stringent CO_2 emission standards, as they integrated EV-specific incentives mechanisms.[13] In that year Europe was the largest EV market. Its EV sales share tripled and reached 10% (IEA, 2021b and this assessment). In 2021, the same trend occurred in China, where the EV sales share tripled over the previous year, reaching 15% (IEA, 2022 and this assessment). EV sales accelerated significantly in 2022 also in North America and Korea, with EVs reaching 7% and 10% of the market, respectively. In other developing and emerging economies, EV sales shares are still below 2%. Despite this, EVs accounted for 14% of all new LDV sales globally. Of these, two-thirds are pure battery electric vehicles while the rest are PHEVs (IEA, 2023b and this assessment).

2.4 VEHICLE SALES BY SEGMENT

International regulations define passenger cars as power-driven vehicles with four or more wheels destined primarily for the carriage of people (UN, 2005, UN, 2023). The passenger car market is divided into different segments, based on vehicle size and shape. Conventional cars typically include sedans, hatchbacks, or multipurpose vehicles. Larger forms of passenger cars, with higher ground clearance and height and that may have initially been designed to be able to drive off-road, include the so-called Sport Utility Vehicles (SUVs) and, in specific markets (mainly in North America) also pick-up trucks.

For the purposes of this report, the passenger car market is divided into five categories: small, medium, and large conventional cars and small and large SUVs. Efforts were made to harmonize segment definitions across all vehicle markets.

All else held equal, SUVs tend to have a higher specific energy consumption than cars, due to a larger cross-sectional area (which increases air drag) and larger weight (which increases the energy needed for acceleration, i.e. to overcome inertia). Light commercial vehicles (LCVs) are primarily intended for the carriage of goods. They tend to be larger than cars and have more space for freight than for passengers, but they also share many of the technology characteristics (especially in terms of powertrains) of cars and, for this reason, are often subject to similar regulatory requirements. Table 2 shows popular vehicles of these categories in each of the main car markets.

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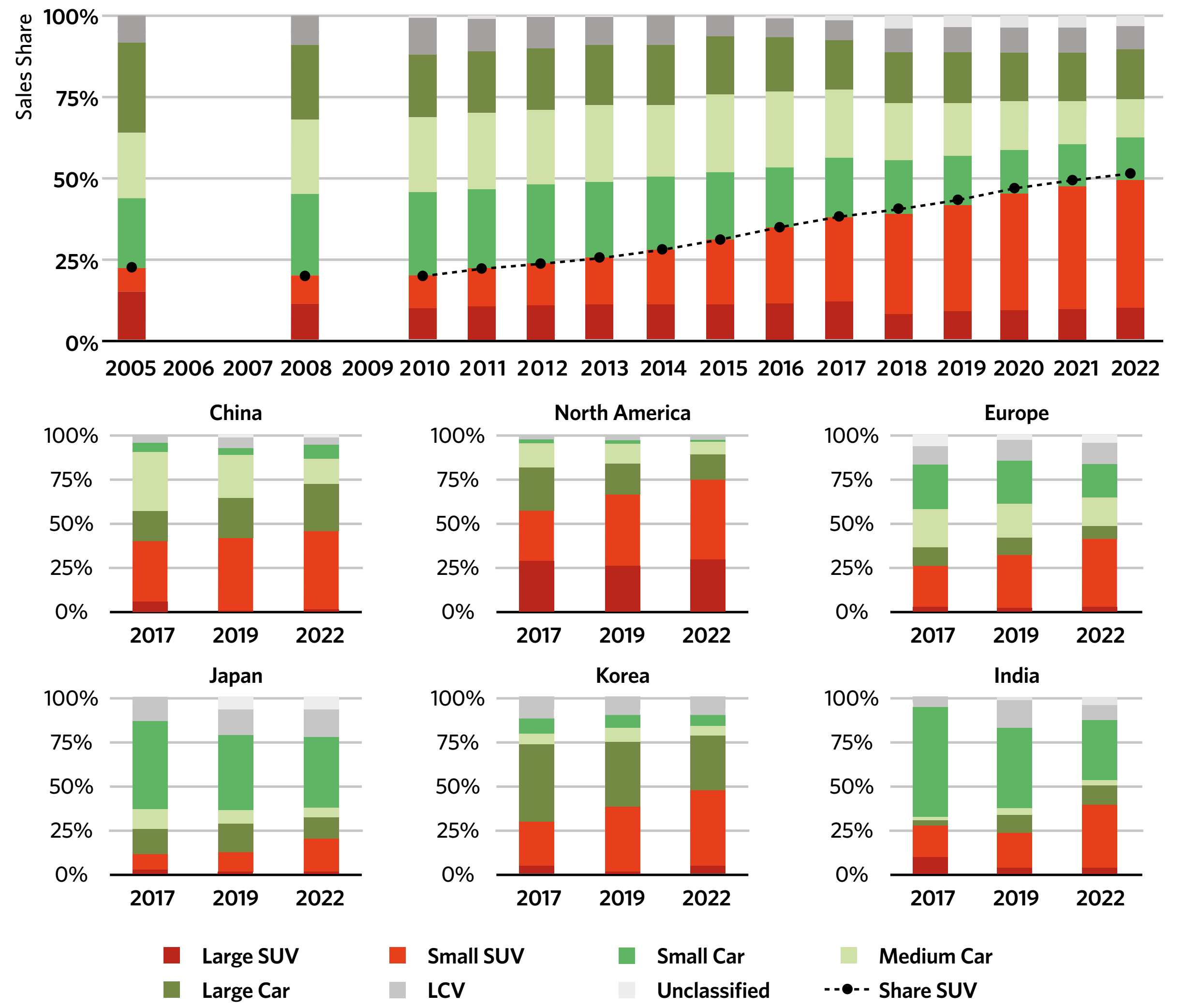
TABLE 2: Top selling vehicle models by segment in key markets

Market	Small car	Medium car	Large car	Small SUV	Large SUV	LCV
China	Wuling Hongguang Miniev	VW Lavida	Toyota Camry	Haval H6	Li L9	Foton Xian-gling M1
Europe	Fiat 500	VW Golf	Audi A4	WV T-Roc	BMW X5	Renault Trafic
United States	Kia Rio	Toyota Corolla	Tesla Model 3	Chevrolet Equinox	Ford F-150	Ford Transit

Figure 8 shows global LDV sales by market segment, clearly illustrating that the main development observed over the period covered by this analysis (2019-2022) has been an increase in the share of SUVs and a corresponding decrease in the sales of cars (especially small and medium cars). On the global scale, SUVs saw their market share rise from 22% in 2005 to roughly half of the LDV market (including cars, SUVs, and LCVs) in 2022.

In addition to an increase across all major markets in the market share of SUV, Figure 8 – which includes details for the main global automotive markets – also shows significant differences in market segmentation across countries.

FIGURE 8: LDV sales by segment: global and in selected markets



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

The United States is the country where SUVs account for the largest share of the market (75% in 2022); Canada and Australia have similarly high SUV shares (79% and 76% in 2022, respectively) (not shown in Figure 8). The North American vehicle market is also characterized by the highest share of Large SUVs, which include vehicles that are locally defined as "full sized SUVs" and "pick-ups," and are not common in other parts of the world. Large SUVs accounted for one quarter of all vehicle sales in 2022. Growth in these segments has remained strong, with the overall SUV market share increasing by 9 percentage points from 2019 to 2022.

In China, SUVs accounted for 45% of the market in 2022, a share that increased by 4 percentage points from 2019. Nearly all SUVs sold fall in the small SUV category, as is the case in most other global markets. Large cars also account for a significant share of the market (26%) in 2022, up by 3% since 2019. China has witnessed, over the past decades, not only a surge in vehicle demand, but also a fast transition from smaller vehicles to larger ones, as the disposable income of its citizens rose.

Europe's share of SUVs is the lowest among the three largest global markets, accounting for 41% of all sales. However, SUV sales in Europe have also consistently grown since 2017. Conventional cars still account for the majority of vehicles sold, however the share of medium cars has been shrinking fast, while small SUV sales increased.

The Korean market has shown similar recent trends in segmentation as Europe, with the exception of the relative shares of conventional cars; large cars have larger market shares in Korea, and shares of small and medium cars are smaller.

Japan has similar market segmentation characteristics to Europe, but the share of small cars is even greater, and that of SUVs even smaller. Europe and Japan share a high reliance on oil imports. The significant resilience of small cars also points to a strong peculiarity of the Japanese market.[14]

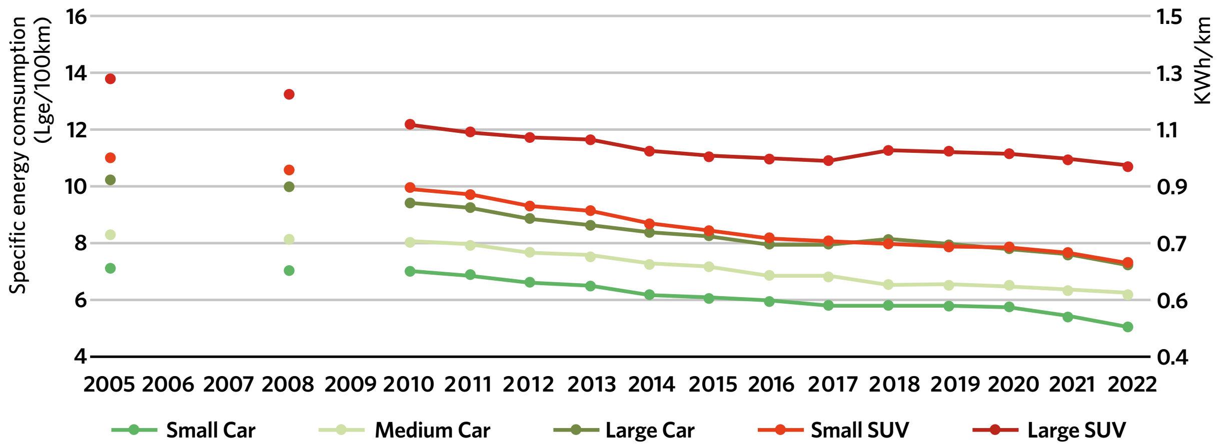
India also has high shares of small car sales, following a long-standing tradition of high fuel taxes and domestic manufacture of small vehicles. Recent market developments, however, show an erosion of market shares of small vehicles, in favour of large cars and small SUVs.

Specific energy consumption varies significantly by vehicle segment: large SUVs are the most energy intensive type of vehicle, while small cars are the most efficient (Figure 9). Small SUVs and large cars are roughly equivalent since the former tend to have higher weight and larger cross-sectional area, while the latter tend to have higher power ratings. When looking at trends, it becomes clear that not all segments have improved at the same rate. In the period 2010 to 2019, small SUVs have undergone the fastest efficiency improvements, as this segment transitioned and evolved from a niche composed mostly of smaller 4x4 vehicles to the world's most popular segment. The specific energy consumption of small SUVs improved by 3% per year, while all other segments improved at rates between 1% and 2.5% per year. In the period between 2019 and 2022, the strongest efficiency improvements have been observed in small cars, with specific energy consumption declining at a staggering 4.3% per year in the case of small cars, driven mostly by rapid adoption of electric cars, in particular in China.

As explained in Section 2.3, electric powertrains significantly reduce energy consumption. However, their market penetration is not equally distributed across segments, nor across geographies. In China, EVs accounted for three-quarters of small car sales in 2022 (Figure 10), with the Hongguang mini EV, a sedan with a top speed of around 100 km/h that sold from around USD 6,500 to up to USD 15,000, being the top-selling model both in 2021 and 2022 (van Vyk, 2023). Chinese automakers have been competing intensely for market share in the small electric car segment, and have been willing to sustain tight margins; Wuling further cut the starting price of the Hongguang mini EV to around 4,300 USD in May 2023 (Reuters, 2023). EVs sold in other segments are often sold at far higher price points, either by established EV leaders such as BYD and Tesla or by new market entrants such as Nio, Li Auto, and XPeng, who have yet to post profits (Leplâtre, 2023).

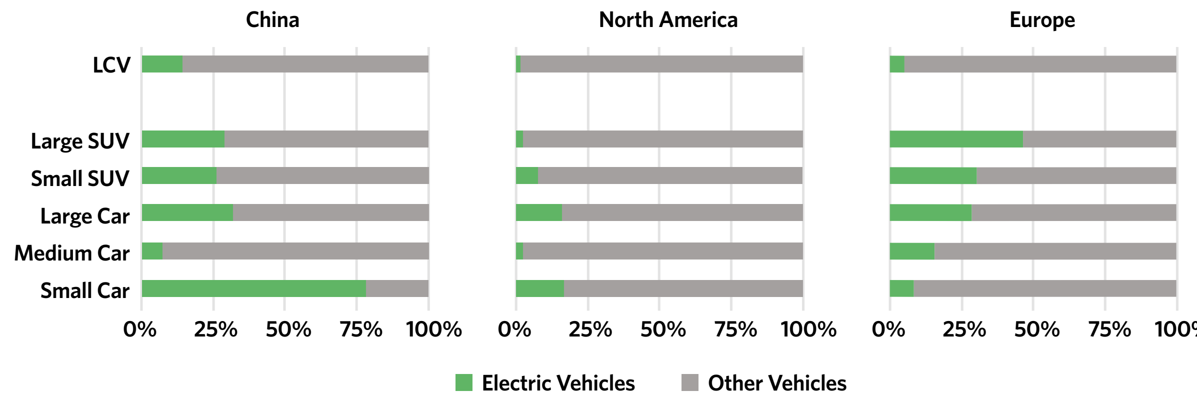
In Europe and the United States, the share of electric sales in the small car segment is far lower than in China (Figure 10). In Europe, large SUVs are the most heavily electrified segment, with nearly half of all sales being electric, followed by the much larger segment – in terms of sales volumes – of small SUVs; with European automakers apparently seeking to replicate the possibility to lock-in higher margins by selling more SUVs even in the rapidly electrifying market. North America sees a different dynamic, where EVs are mostly found in small and large cars (with Tesla leading in the large car segment). Across all three markets, the medium car segment has relatively low levels of EV penetration.

FIGURE 9: Global specific energy consumption by vehicle segment



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE 10: Electric vehicle sales share by vehicle segment in key automotive markets, 2022



Note: Electric vehicles include plug-in hybrid and battery electric vehicles.

Source: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines

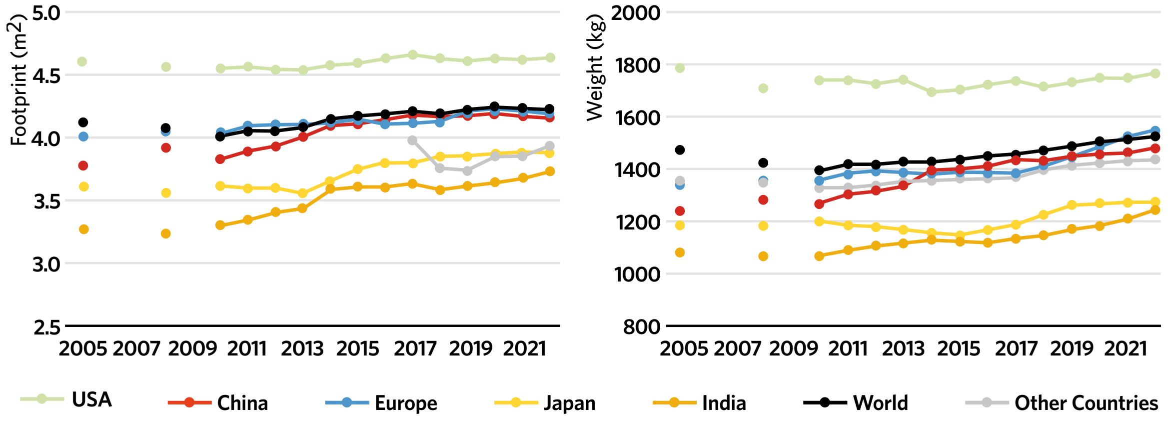
2.5 VEHICLE SIZE AND WEIGHT

Two major global trends are affecting the average vehicle size (best represented by the attribute of footprint)[15] and weight[16] are the shift of market segments towards SUVs and electrification.

Both weight and footprint have been on the rise since 2010 (Figure 11), the year that also marks a change in pace in the transition across market segments globally (Figure 7). The shift from (especially small and medium) cars to SUVs has been a key driver of larger average footprint and greater weight.[17] As shown in Table 3 and Figure 5, for ICEVs this shift is also associated with systematic differences in specific fuel consumption across segments, pointing to a key role of the shift in market segmentation in limiting energy efficiency improvements for LDVs.

Recent developments, however, following the year 2020, also suggest that the increasing trend for vehicle footprint has slowed down, and vehicle size even experienced a slight decline in 2022 (Figure 12). Vehicle weight, on the other hand, continued to increase. A major determinant of this development is the adoption of EVs. The reason is that EVs tend to have similar dimensions (and footprint) to ICEVs, but greater weight, largely due to the heavy battery that they carry (as further detailed in Chapter 3).

FIGURE 11: Footprint and weight trends across major LDV markets



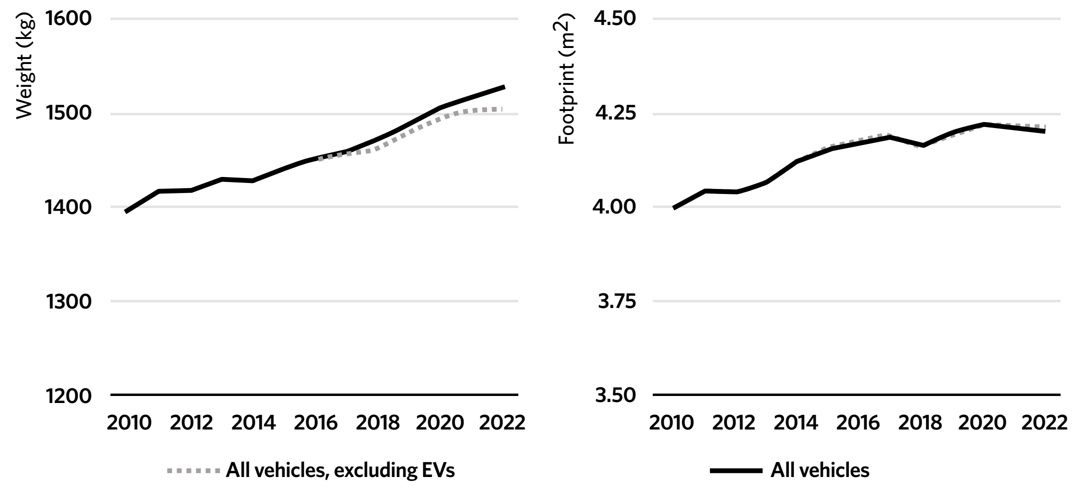
Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

TABLE 3: Average vehicle characteristics by segment (left) and change in sales share by segment (right)

World	Average footprint	Average weight	Specific Energy Consumption		Market share change	
	m²	kg	Lge/100km	kWh/km	2010-2017	2017-2022
Small car	3.5	1050	4.9	0.46	-9%	-3%
Medium car	4.0	1350	6	0.56	-3%	-8%
Large Car	4.5	1660	6.5	0.60	-3%	-1%
Small SUV	4.1	1520	6.6	0.61	19%	10%
Large SUV	5.2	2140	10.5	0.98	-2%	1%
LCV	4.4	1670	7.6	0.71	18%	11%

Source: this assessment (details in the Annex) based on EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE 12: Global vehicle weight (left-hand side) and footprint (right-hand side) trends, including and excluding EVs



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

3 ANALYSIS OF THE VEHICLE MARKET DEVELOPMENTS AND IMPLICATIONS FOR POLICY ACTION

This Chapter focuses on the two major trends identified in Chapter 2: a shift in market segments towards SUVs and a recent rapid development of vehicle electrification. The analysis considers the impact of both these developments on energy use per km, direct CO_2 emissions, road safety, and equity. Specific sections cover the implications that the EV transition had on the SUV shift, and makes the case that the combined shift to SUVs and the EV transition are leading to increased risks of a global divide. The last section lays out reasons that justify the policy interventions elaborated in Chapter 4.

3.1 IMPACTS OF THE SHIFT TOWARDS SUVS

This section outlines impacts that the shift towards SUVs had on energy, direct CO_2 emissions per km[18] and vehicle weight, also considering related implications for road safety and equity.

3.1.1 ENERGY AND CO_2 EMISSIONS

Figure 13 shows historical evolutions in specific energy consumption for the main automotive markets globally, comparing developments in cases that include or exclude a shift in market segmentation, taking the year 2010 as the baseline. The data indicate that energy use per km for ICE vehicles without the shift towards SUVs (and the subsequent increases in vehicle size, weight and power) could have improved at an average annual rate that is 30% higher than it actually did.[19] The gap is larger in China (around 50%) and narrower in Europe (around 20%), as the first focused on EVs while the other focused on improved technologies for ICEs (as discussed in Section 3.3.).

Gaps in terms of direct emissions of CO_2 are even larger, as CO_2 emissions are almost directly proportional to fuel use for ICEVs,[20] and EVs do not emit CO_2 at the tailpipe. Gaps are slightly narrower with lifecycle accounting of greenhouse gas emissions, as:

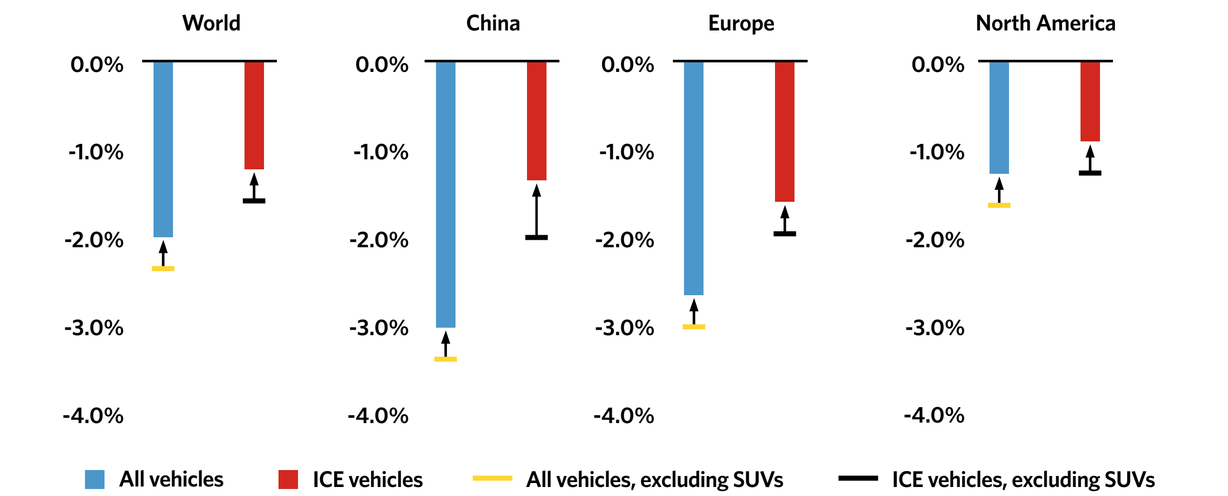
- Light-duty EVs have significantly lower lifecycle emissions, over their lifetime, with respect to ICEVs (Bieker, 2021), but the lifecycle emission gap, especially in places with carbon-intensive grid mixes, is not as wide as the energy efficiency differential.
- The variation of specific energy consumption for EVs across vehicle segments is small (as shown in Figure 5 for the case of Europe for 2022, and as also shown in IEA, 2019a, with data from different geographies).

3.1.2 VEHICLE WEIGHT

Figure 14 illustrates trends in vehicle weight, globally and in the main markets, excluding the effect of the EV transition (discussed in Section 3.3.2), but including the impacts of the SUV shift. As SUVs are heavier than small and medium cars (Table 3), and as the main shifts in market segmentation consist of a decline in sales share of small and medium cars and an increase in small SUV sales shares, the data in Figure 14 indicate that, in the absence of the SUV shift, vehicle weight increases could have been more than halved relative to the increase that actually occurred (when excluding impacts of the EV transition) between 2010 and 2022.

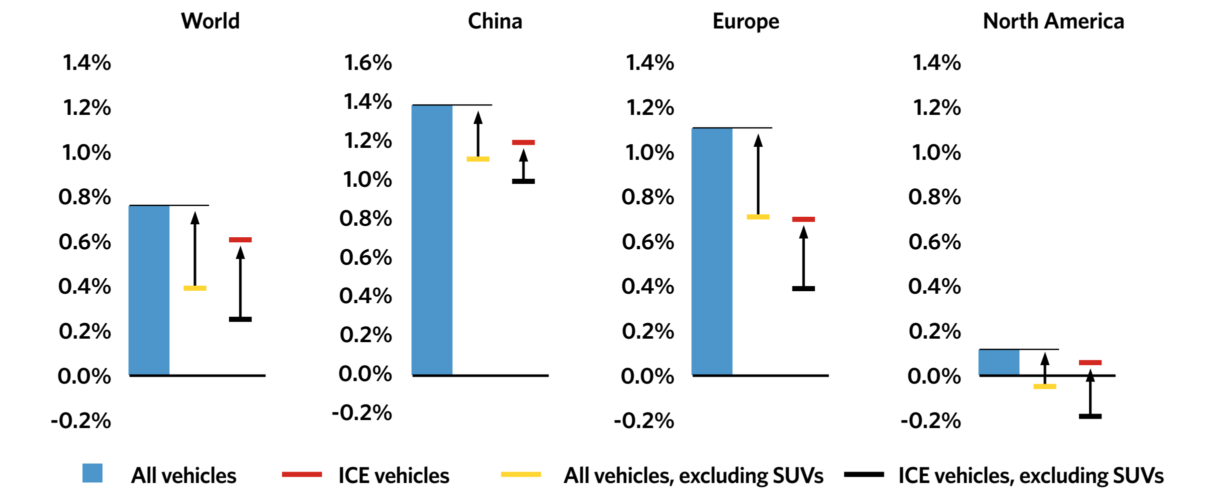
Region-specific results shown in Figure 14 indicate that net savings in weight (and related material demand) could have been stronger, in percentage terms, in Europe and China than in the United States. They also indicate that weight increases have been more pronounced, over time, outside of the United States, even if average LDV weight in the North American market is still well above all others in absolute terms (by about 15-20%).

FIGURE 13: Global yearly rate of change in specific energy consumption, with a focus on the impact of the SUV shift, 2010-2022



Note: Observed rate is the yearly rate of improvement in SEC. Without EV, with SUV: is the rate of improvement that would have been achieved without EV (BEV and PHEV) sales. Without SUV, with EVs: is the rate that would have been achieved if LDV segment share had remained the same as it was in 2010. Without SUV, without EVs: is the rate that would have been achieved with the same LDV segment sales share as 2010 and without EV sales.
Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE 14: Rate of change in vehicle weight, with a focus on the impact of the SUV shift, 2010-2022



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

3.1.3 ROAD SAFETY

The shift to SUVs also had implications for road traffic injuries. Worldwide, road traffic injuries are the leading cause of death for children and young adults aged 5-29 years, and the cost of road traffic crashes is estimated at around 3% of GDP across most countries (WHO, 2022).

Studies analysing the impact of increases in vehicle weight and size on motorist, passenger, and pedestrian safety show that collisions with larger, heavier vehicles are more likely to result in more severe injuries (including brain damage) or death, both to drivers of smaller vehicles and to cyclists and pedestrians (Ossiander at al., 2014; Van den Berghe, 2021; Edwards and Leonard, 2022, Nuyttens and Ben Messaoud, 2023). Such studies primarily focus on the impacts of larger and heavier cars in North America (and especially in the United States – where car crashes are among the leading causes of death) and Europe.

Recent analyses conducted in the United States find that large trucks, minivans and SUVs do not necessarily make the roads more dangerous, in aggregated terms, for drivers or passengers. However, risks are distributed unevenly. Increased injury and mortality rates for occupants of smaller vehicles are generally offset by lower rates for occupants of larger vehicles (Ossiander et al., 2014).

In addition to their greater weight and size, pickup and SUV designs diverge somewhat across key parameters that influence crash safety (for instance ride height) from cars. In the United States, this design incompatibility has decreased following a 2009 voluntary commitment among automakers to standardize the height of energy-absorbing structures across all vehicles. Nevertheless, weight differences, together with some degree of continuing incompatibility, increase mortality risks for drivers of cars in crashes between pick-ups or SUVs and cars by around 25% (Monfort and Nolan, 2019).

Evidence also shows that the severity of injuries and the risk of mortality is substantially higher for pedestrians that are hit by minivans, pickups, and SUVs, due to factors such as greater impact force, higher front-end designs, and larger driver blind spots (Tyndall, 2023, Nuyttens and Ben Messaoud, 2023). In the United States, pedestrians hit by a pickup truck are roughly 70% more likely to die than those hit by a car, and those hit by an SUV are twice as likely (Tyndall, 2023). If all light trucks (minivans, pickup trucks and SUVs) sold from 2000-2019 had been cars, pedestrian deaths in 2019 could have been reduced by 30% (Tyndall, 2021).

3.1.4 EQUITY

The analysis developed by the IEA and the ICCT in 2017 (as summarized in Figure 15) shows that vehicle prices tend to be higher, across all main automotive markets, for small SUVs – the segment that keeps experiencing significant increases in market shares – than for small and medium cars – the segments that, globally, experienced the most relevant contractions.

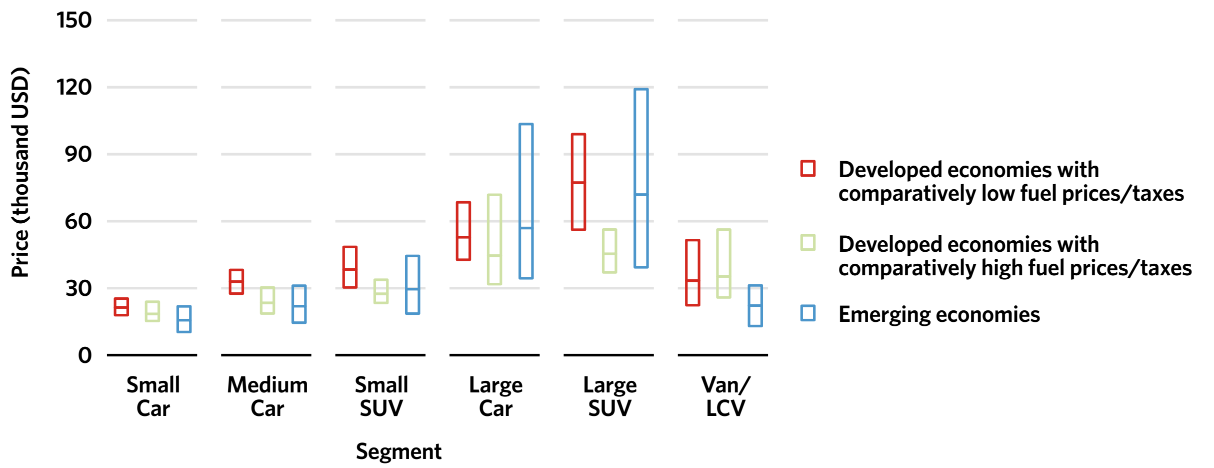
Taking central estimates, for all regions, the gap between a medium car and a small SUV price is on the order of 10% to 20%, and 25% to 60% between a small car and a small SUV, with the largest gap in developed economies with low fuel taxes (IEA, 2019a).[21] Similar gaps emerge from a recent comparison between small/medium cars and small SUVs for different European brands and models, which found that small SUVs carry a price premium of 8% to 30% with respect to comparable small and medium cars (Krajinska, 2023).

Figure 16 indicates also that ICE powertrain costs make up lower shares of the total vehicle price for small SUVs with respect to small and medium cars. This suggests that a shift in market segmentation towards SUVs, without major changes in powertrain technology, is not only likely to lead towards increases in turnover, but also towards larger profit margins, for manufacturers. Such a development is confirmed also by analyses pointing to larger margins available for larger, premium ICEVs (Sussams et al., 2018; Slowik et al., 2022). This is also consistent with reports showing increases in OEM profits, even with declining sales (Welch and Naughton, 2023 and Hersh, 2023).

Combining these estimates with the decade-long tendency of a global shift towards SUVs shows clearly that the resulting impact led to significant increases in OEM revenues with respect to a counterfactual without the shift. Drawbacks related to potential market growth higher than what has been observed are possible and are also consistent with the increases in average vehicle age in replacement markets like the EU and North America (European Environment Agency, 2023, for Europe and Parekh and Campau, 2022, for the United States),[22] even despite increases of average income levels, which provided households with a larger budget for vehicle purchases). The significant price gaps shown in Figure 15, combined with a continued expansion in SUV sales shares, are also consistent with the increased profitability registered by the automotive industry after 2020, taking place even with a decline in sales volumes (Stricker and Correa, 2023), and notwithstanding a contextual effect due to increased inflation.

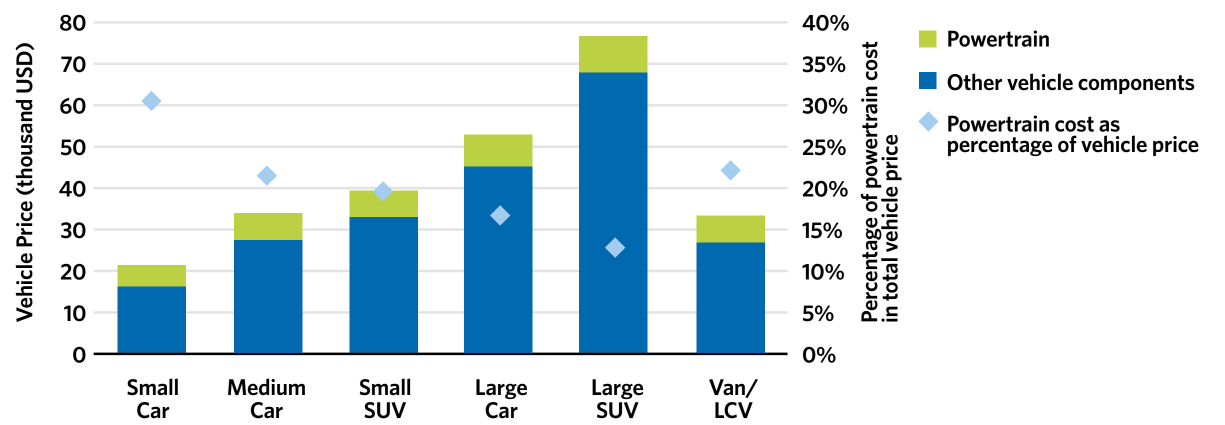
This also resulted in relevant affordability and equity challenges, within and across countries. Since 2019, average new car sales prices have risen faster than inflation in most regions. For example, the average price of new cars in the United States in early 2023 was 30% higher than in 2019 (this compares prices of the same cars, and hence is not a result of the shift to SUVs) (Bureau of Labor Statistics, 2023). New car buyers tend to be higher-income households (Krisher, 2022) that can afford larger and more expensive vehicles. However, the choices made by this segment of the population affect the choices and affordability of car sales for the second-hand market (see, for instance, Krisher, 2022).[23] The lower-income segment of the population that relies on the second-hand market is also likely to be affected by the recent average price increase of vehicles, which was compounded by a shift towards SUVs.

FIGURE 15: Evolution of vehicle prices, by segment and economic cluster, for the year 2017



Source: adapted from IEA, 2019a, with revision of labels used for vehicle segments to match names used in this report.

FIGURE 16: Share of powertrain costs in internal combustion engine vehicle price for different vehicle segments



Source: adapted from ITF, 2020a, with revision of labels used for vehicle segments to match names used in this report.

This effect is stronger in high-income countries, where there is a higher share of SUV sales. However, data shows that the move towards larger market segments is a global phenomenon. Data on vehicle prices by segment and global region, available from IEA, 2019a (and shown in Figure 15) show a clear price gap between cars (especially small and medium cars) and small SUVs. As sales shares of small and medium cars shrink and shares of small SUVs rise, equity impacts are also likely to emerge.

The dynamics of segment shifts in low- and medium-income countries are the combination of different factors that vary country by country:

- New car buyers in low-income countries tend to represent a small and very high-income segment of the population, therefore their high budget availability and preferences lead them to purchase increasingly large vehicles. In such countries, lower income segments of the population do not have the financial ability to enter the new car market, therefore the demand for smaller, more affordable new cars is weak.
- In medium-income countries, where vehicle ownership is on the rise and demand growth is strong, small and medium cars are retaining market share as first-time new car buyers in these countries are more likely to be able to afford smaller vehicles. The rapid growth dynamics also mean that OEMs can retain sufficient profit margins. Both justify lower SUV market shares, in comparison with high-inciome countries.

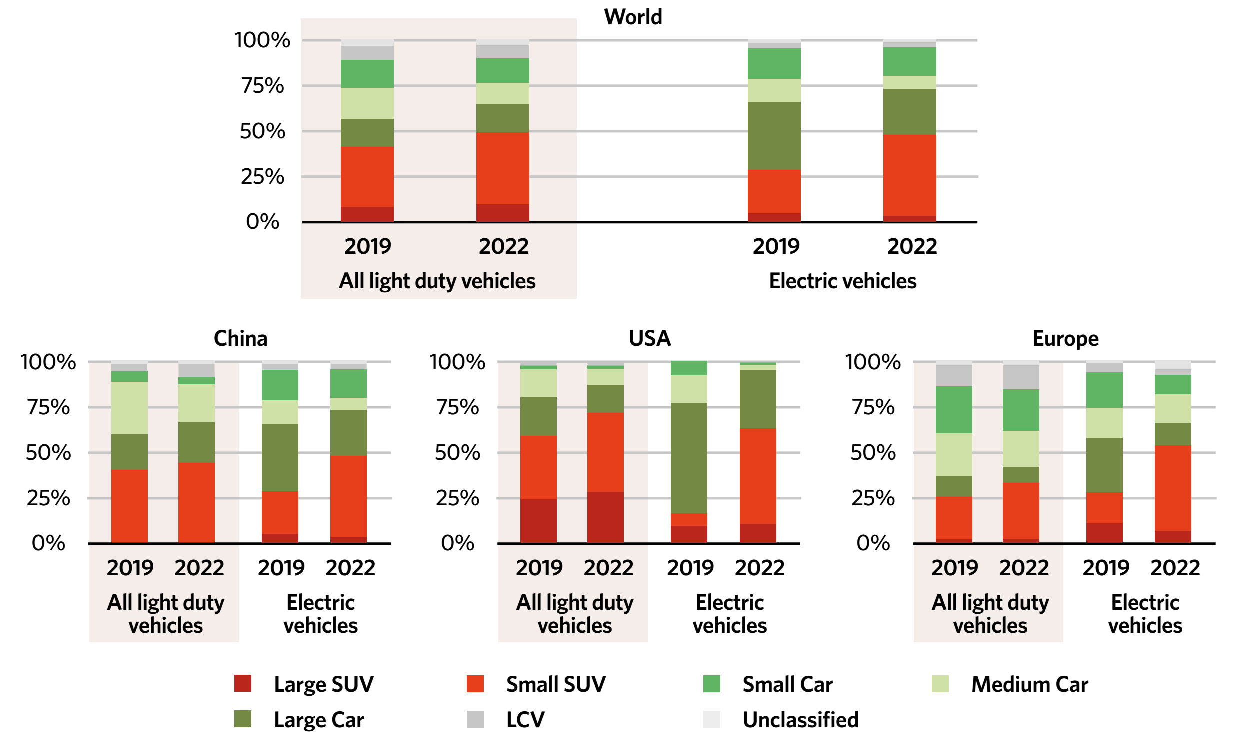
Equity impacts due to increases in new vehicle prices in developed countries may also impact second-hand vehicles sales in low- and medium-income countries, where second-hand vehicle purchases are a more common path to access motorization. Therefore, a higher average price of imports driven by an increased availability of larger cars exports can lead to greater challenges in gaining access to motorized mobility in countries strongly reliant on second-hand vehicle imports. Due to greater constraints in the range of mobility choices, equity impacts due to vehicle price increases are also more relevant in countries with limited affordable, accessible, and reliable alternatives to personal vehicles (such as public transport).

3.2 THE ROLE OF EVS IN THE SHIFT TOWARDS SUVS

Figure 17 provides additional insights across the main global markets compared to the information already shown in Figure 10.[24] The figure illustrates the evolution of market segmentation across all powertrains (left-hand bars) and for EVs (right-hand bars), between 2019 and 2022. The figure shows that EVs are not exempt from the shift towards SUVs: the market share of electric SUVs (especially small electric SUVs) has grown substantially between 2019 and 2022, in all markets. This marks an increase in product diversification, as EVs also gained overall market shares, moving beyond earlier market deployment strategies, more focused on large, premium car models.

EV shares declined in the small car segment between 2019 and 2022, across all markets. This is primarily due to shifts in Europe and the United States (where this was further exacerbated, in 2023, by discontinuation of the only electric small car by a US OEM). As shown also in Figure 6, EVs in the small car segment maintained significant market shares in China. Globally, EVs also have limited market share within the large SUV segment. This is consistent with sizable market shares of large SUVs limited to North America, where EVs also had – to date – lower market penetration, in comparison with China and Europe (despite recent increases).

FIGURE 17: Powertrain shares globally and in major EV markets globally, with EVs singled out, 2019 and 2022



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

3.3 IMPACTS OF THE EV TRANSITION

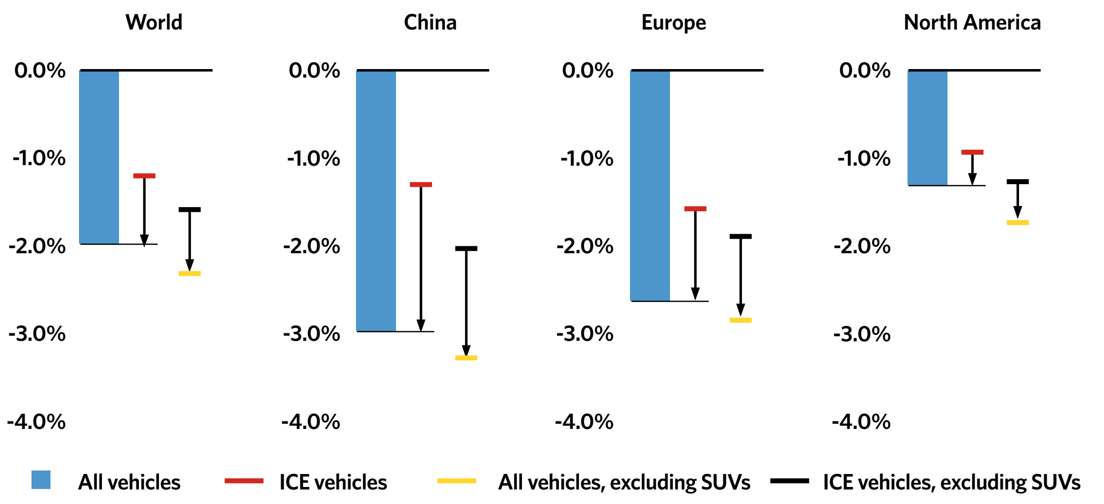
Similar to the case of the SUV shift covered in Section 3.1, this section assesses impacts on the EV transition on energy and CO_2 emissions, weight and material needs, road safety, and equity in different sub-sections.[25]

3.3.1 ENERGY AND CO_2 EMISSIONS

Chapter 2 highlights the key role EVs have played in reducing the specific energy consumption of vehicles after 2020. Section 3.1.1 discusses impacts of the shift towards SUVs on energy efficiency and CO_2 emission trends, excluding the effect of electrification, pointing out that the SUV shift led to significant reductions in the rate of improvement of energy efficiency compared to what could have materialized without this shift, and resulting in upward pressure on energy demand and CO_2 emissions.

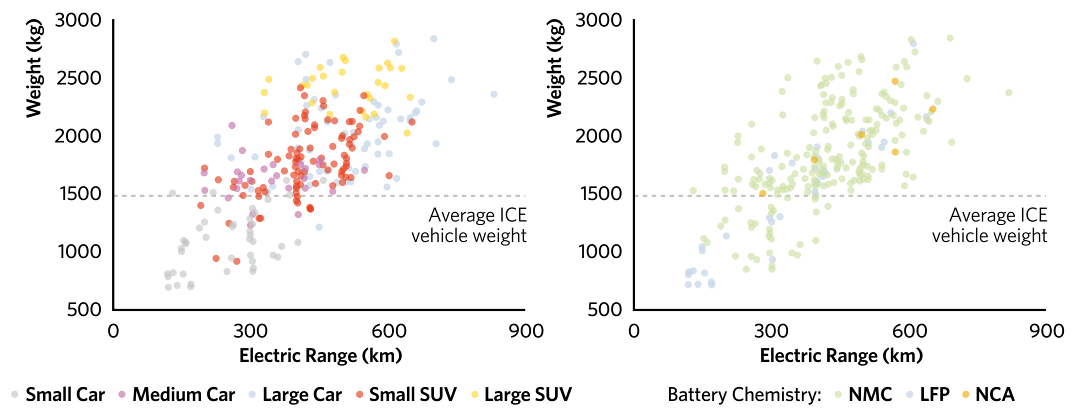
This section analyses the specific effect of increased EV deployment on the gap in energy use per km (outlined in Section 3.1.1), considering the impacts on specific energy consumption of the shift to SUVs in EVs. Like Figure 14, Figure 18 shows historical evolutions in specific energy consumption for the main automotive markets globally, comparing developments that actually occurred with a counterfactual that excludes the shift in market segmentation (on the top of the results already included in Figure 14).

FIGURE 18: Global yearly rate of change in specific energy consumption, with a focus on the impact of the EV transition, 2010-2022



Sources: this assessment (details in the Annex) based on IEA, 2019a; IEA, 2021a; EEA, 2023a; EEA, 2023b and Marklines data.

FIGURE 19: Weight as a function of electric range for battery electric vehicles



Source: analysis based on data from EV Volumes (EV Volumes, 2023).

Overall, results shown in Figure 18 point toward net increases in energy savings from EVs, across all markets. Without EVs, savings would have been 40% lower at the global level.

The role of EVs is the result of two effects. On one hand, EVs have markedly lower specific energy consumption versus competing technologies (see also Figure 5, showing this clearly for the case of the European market). On the other hand, like all vehicles, specific energy consumption for EVs also increases with increasing vehicle weight (and therefore also with the segment shift towards SUVs), even though these increases are less pronounced than for other powertrains.

Energy savings due to EVs are stronger in recent years and in markets that saw a larger EV market penetration. In China and Europe, electrification had a very strong role in the decrease of average specific energy consumption of new vehicles. In the United States, impacts of the EV transition on trends of specific energy consumption are less pronounced, due to lower EV market shares as compared to China and Europe. From 2020 to 2022, electrification led to reductions in specific energy consumption that were roughly offset by the detrimental impact of SUVs.

3.3.2 VEHICLE WEIGHT

EVs are on average 13% heavier than equivalent ICEs. The differential in weight for EVs comes primarily from the weight of the battery, which in turn depends on three factors: specific energy consumption, battery technology, and range.

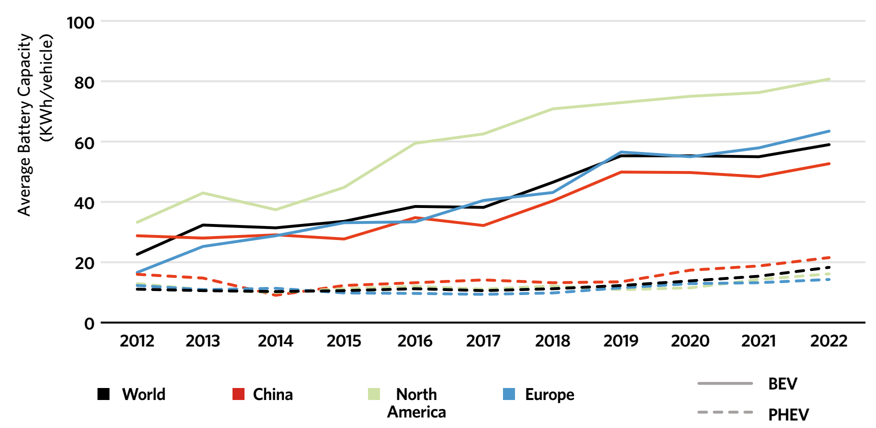
Despite lower impacts on EVs, due to the possibility to recover energy in regenerative braking, specific energy consumption for EVs still varies across market segments. European data (Figure 5) show that small BEVs consume less energy, on average (14-15 Wh/km), than large all-electric SUVs (18-20 Wh/km). Small EVs also have lower vehicle weights than large EVs, as they need smaller batteries for the same range (Figure 19). Motor technology can also contribute to weight savings, since higher efficiency motors (usually using rare-earth rich permanent magnets) can deliver better specific energy consumption.

Battery technology (including chemistry and pack architecture) matters for vehicle weight because it determines the energy density of the battery (Wh/kg). Better technologies deliver more energy per unit weight and tend to be used more frequently on larger vehicles, with longer ranges (Figure 19). High nickel content chemistries tend to have higher cell-level energy densities that range from 240 to 340 Wh/kg, while lithium iron phosphate (LFP) chemistries range between 150 and 190 Wh/kg (Hasselwander et al., 2023, Battery Design, 2022, Frith et al., 2023). Pack technology is also very important, as there can be significant differences across chemistries, with LFP performing better than other chemistries, as also shown by BYD, with the blade battery (Frith et al., 2023). This opens up opportunities for its use on vehicles with larger batteries and longer ranges.

The electric range of a vehicle is determined by battery capacity and weight (Figure 19), as well as by the vehicle aerodynamics and powertrain efficiency. All else being equal, range is directly proportional to battery capacity, and thus also vehicle weight. Figure 19 shows that, on average, adding 100 km of range adds 330 kg to vehicle weight for a BEV (less additional weight is needed for smaller BEVs, given their lower energy intensity). EVs with ranges below 400 km have a weight that is roughly similar to average ICE vehicles, while for longer range vehicles, weight rapidly increases.

The relevance of range as a key determinant of battery size is also important considering PHEVs and BEVs independently, since PHEVs are meant to rely on all-electric ranges mainly for trips with shorter distances – and therefore have smaller battery packs (Figure 20) – while they still rely on the HEV powertrain in charge-sustaining mode for longer distances.[26] As such, they come with the advantage of lower requirements in terms of battery materials, with respect to BEVs, and the disadvantage of having a weight penalty due to the ICE.[27]

FIGURE 20: Average battery capacity for PHEVs and BEVs globally and in the main LDV markets



Source: this assessment (details in the Annex) based on EV Volumes (EV Volumes, 2023).

BOX 2:

REDUCING CRITICAL MATERIAL REQUIREMENTS FOR EV BATTERIES BY REDUCING BATTERY SIZES

EV battery cathodes require high purity "critical materials" including lithium, cobalt, manganese, and nickel. Magnets that are in most EV motors (except for AC induction motors) require rare earth elements (mainly neodymium, and often also dysprosium, terbium, and praseodymium).

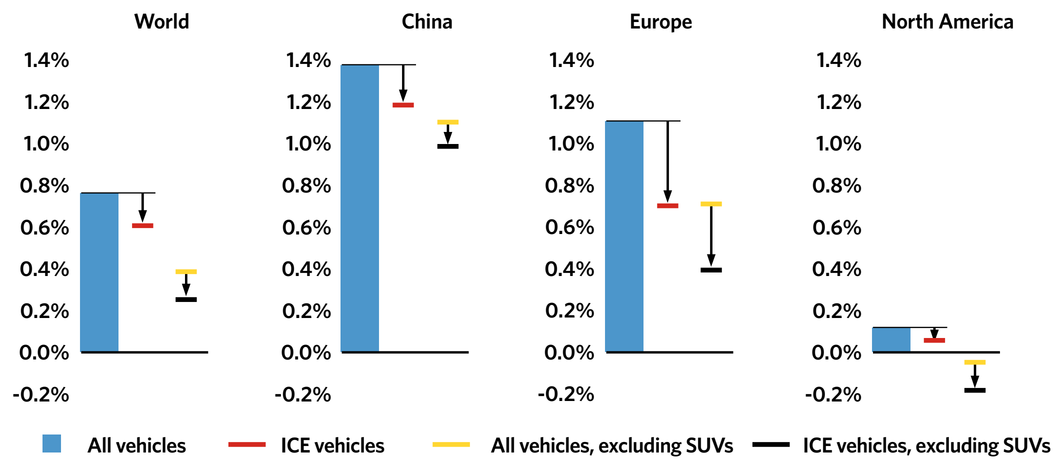
A massive scale-up of critical material mining, processing, and EV cell production will be required over the coming decade to enable the rapid growth of EVs required to meet global climate targets (IEA, 2023c). Scaling up to levels where supply can match demand growth will require closing gaps between global supply (based on expansion announcements) and EV battery demand, as well as ensuring that each step of the EV battery supply chain — mines, material processing, cathode and anode production and cell production — ramps up to full capacity at speeds equivalent to or better than what has been achieved to date. The supply gap for lithium is particularly acute – IEA assessed the gap between EV battery requirements in the Net Zero Scenario and announced production plans to 2030 to be just under 40% for lithium mining and processing (IEA, 2023c).

Rapid acceleration in EV demand, bolstered by ambitious EV deployment and industrial policies and targets, has already begun to guide investment for new facilities, as well as development of innovative chemistries such as sodium-ion batteries for vehicle applications (Tapia-Ruiz et al., 2021). These are being explored by several Chinese battery makers, and are most viable in small EVs (as well as in electric two-wheelers due to lower energy density and lower cost).

For a given battery chemistry, mineral intensity scales linearly to battery capacity at the cell level. For example, 0.1 kg of lithium are needed per each kWh of capacity for NCA and NMC 811 cell chemistries (the intensities are similar for LMO, at 0.106 kg/kWh, and for LFP, at 0.095 kg/kWh).

Demand-side opportunities for right-sizing batteries could also help to close the material supply gap, as well as decrease risks posed by regional concentration of lithium (and other metal) mining and processing. For instance, returning to average battery capacities of around 40 kWh/vehicle (the global average in 2017), rather than 60 kWh/vehicle (the average in 2022 – as shown in Figure 20), would reduce lithium demand by around one-third. Other demand-side measures, such reducing reliance on car ownership, together with EV battery recycling, could further reduce exposure to critical mineral risks (Riofrancos et al., 2023).

FIGURE 21: Rate of change in vehicle weight, with a focus on the impact of the EV transition, 2010-2022



Source: this assessment (details in the Annex) based on EEA, 2023a; EEA, 2023b and Marklines data.

Figure 21 shows weight trends, globally and in the main light-duty vehicle markets, considering both the SUV shift and the EV transition, similar to Figure 18 for specific fuel consumption. The indications emerging from Figure 21 are consistent with the considerations outlined in Chapter 2 and above, since they indicate that the EV transition led to net increases in weight trends, adding to the effect of the shift from small and medium cars to SUVs.

The effect is remarkable in the case of Europe, characterized by rapid growth both in EV shares and by higher EV penetration in the SUV segments. China exhibits a lower weight increase due to its EV transition, reflecting the fact that the majority of EV sales are in the small segment (Figure 10). In the case of North America, impacts of the EV transition are larger when the SUV segment shift is not taken into consideration, since EVs have mostly penetrated in small and large car segments to date.

3.3.3 ROAD SAFETY

Chapter 2 – in particular Section 2.5 – shows that vehicle electrification is having a significant effects on vehicle weight, contributing to the continuation of an upward trend, despite a flattening of the evolution of vehicle footprints. This contribution means that EVs are clearly not exempt from implications related to road safety. Available data on road safety point to a likelihood of passengers being killed in a collision with another vehicle that increases by 12% for every 500 kg difference between vehicles (Shaffer et al, 2021). This is also what explains increased injury and mortality rates for occupants of smaller vehicles in crashes with larger vehicles, as flagged in Section 3.1.3 and as also reported in Nuyttens and Ben Messaoud (2023) for the case of Belgian roads.

A 2018 study by the Insurance Institute for Highway Safety, focused on the United States, found that hybrid vehicles were subject to a 10% higher likelihood to injure a pedestrian than ICE equivalents (Highway Loss Data Institute, 2018). Extrapolating this result on the basis of characteristics like faster acceleration and lower noise, Zipper (2023) claims that similar impacts could also end up being observable for EVs. Lower noise is effectively identified as a reasonable cause of higher frequency of crashes between EVs and pedestrians, in the case of Norway (Nuyttens and Ben Messaoud, 2023).

While acknowledging that most countries are still in an early phase of EV deployment, analyses that have reviewed available evidence from road safety analyses regarding EVs in Europe (including Norway) do not point towards indicators of negative impacts from vehicle electrification on road crashes with other vehicles (Nuyttens and Ben Messaoud, 2023). A possible reason for this is the possibility that EVs are more frequently equipped with effective driver assistance features, capable of protecting both occupants of the vehicle and other road users.

Overall, it is therefore important that a transition towards greater shares of EVs can effectively integrate strategies that limits their impact on weight increases (Shaffer et al, 2021), while still delivering the sizable energy security, energy diversification, and GHG emission mitigation benefits that EVs are capable of.

3.3.4 EQUITY

Available data on vehicle purchase prices – such as those outlined in IEA, 2019a and in following techno-economic analyses, including Slowik, 2022, for the United States[28] – point to a significant purchase price premium still characterizing sales of both PHEVs and BEVs. This premium is grounded in a combination of technical and economic factors, including:

- The cost of the batteries, for BEVs, which currently still exceeds the cost of ICE powertrains, and major efforts (including the possibility to develop new joint ventures between battery manufacturers and automotive OEMs) needed to develop new supply chains.
- In the case of PHEVs, the cost of complex powertrains, which combine ICEs with systems meant to pair engines with electric motors and batteries, anyway larger than on hybrids and ICEVs.
- Other cost components, related to research, development and – above all – investment in new industrial facilities, as these come with large capital outlays that need to be recovered over time.
- Especially for legacy OEMs, costs potentially associated (as this varies on a case-by-case basis) with the need for early dismissal of existing industrial facilities, or part of them (e.g., engine production lines), even if other capital costs are likely to be already amortized (contrary to the case of new market entrants focusing exclusively on electric vehicles).

These factors, combined with a near-term focus on higher profitability, also explain the greater reluctance of legacy OEMs to enter the EV market, especially in smaller segments. This is the case despite exposure to long-term losses of market shares to Chinese competitors (already selling EVs at affordable prices, and across several different segments) and prospects for shrinking relevance as automotive technology providers going forward.

The economic benefits of EVs – which consist of lower running costs and a decreased exposure to oil product market price – are benefitting those consumers and small businesses that can afford the higher upfront cost. These tend to be in very high-income segments of the population, meaning that lower income segments of the population are not able to reap the economic benefits of electrification. Therefore, vehicle electrification is not exempt from equity challenges, at least until such a time when EVs no longer come with higher upfront costs.

EV sales are concentrated in China and high-income countries, as higher upfront costs (especially in countries other than China) and lack of charging infrastructure make EV deployment slow in low- and middle-income countries. The same equity issue that exists within individual economies – as low-income groups are not yet able to reap the savings that come with more efficient electric vehicles – also exists at the global level, across countries with different levels of income.

3.4 ARE SUVS AND EVS INCREASING THE RISK OF A GLOBAL DIVIDE?

Equity-related challenges and greater exposure of low-income households and businesses to the combined market transformation towards EVs and SUVs point towards the possibility of a growing global divide, not only within different population groups within countries, but also between major developed economies and other countries.

A number of global dynamics may exacerbate this potential trend:

- Increases in fossil energy prices, already accelerating the transition to EVs, as they tend to be paired with greater exposure to high energy prices on non-EV drivers.[29] resulting in greater challenges to access EVs for households and businesses exposed to higher costs of borrowing, and often reliant on second-hand vehicle purchases.
- Faster depreciation of ICEVs, including SUVs (which are still likely to remain more expensive than conventional cars), with respect to EVs,[30] resulting in greater challenges to access EVs for households and businesses exposed to higher costs of borrowing, and often reliant on second-hand vehicle purchases.
- Growing interest in batteries for stationary applications, as well as regulatory requirements related with materials circularity and a progressive transition towards net-zero emissions, insofar as these policies exert upward pressure on the value of EV batteries and the materials they contain, as these could also slow down EV depreciation, with net advantages for people and businesses having easier access to capital at lower costs.[31]

The impacts of dynamics affecting vehicle prices (via depreciation and/or structural determinants of battery costs) are not only limited to single countries or markets, but they also have transnational relevance, through international trade of new and second-hand vehicles. The latter is especially important for many low- and medium-income countries in Africa, Asia, the Middle East and Latin America, as they receive significant flows of used cars and vans (contributing to ensure a more affordable access to enhanced mobility options)[32] from high-income countries (UNEP, 2021).

In the absence of strong efforts to accelerate the shift to electric mobility in the Global South, at affordable costs, there is an increased risk of a growing divide between vehicle markets in the Global North – more focused on new EV purchases and having greater capital availability to retain second-hand EVs, and other markets – more exposed to EV deployment and increased flows of cheap and unsafe ICE vehicles, including through second-hand vehicle trade.

Rapid declines in new battery costs and/or energy prices (with greater environmental benefits if these declines are faster for renewable energies and/or other forms of low-carbon electricity, in comparison with fossil fuels) could mitigate these effects.

3.5 NEED FOR POLICY ACTION TO ADDRESS EXISTING CHALLENGES

Chapter 2 described key features of recent developments of the light duty vehicle market, providing a global overview that covers vehicle sales trends, powertrain technologies, market segments, specific energy consumption, CO_2 emissions, vehicle weight and footprint. Chapter 3 analysed further specific implications of two major trends identified in Chapter 2: a shift in market segments towards SUVs and a recent rapid development of vehicle electrification.

The analysis developed in Chapter 3 considered key elements that underpinned an increase in market shares of SUVs. It looked at the impact of this development on energy consumption, CO_2 emissions road safety and equity. It overlaid these considerations with transformations due to increased rates of electrification in the global LDV market, pointing out cases where EVs could mitigate or exacerbate challenges arising from the SUV shift.

Overall, this analysis flagged the following key issues, also summarized graphically in Table 4:

- While the shift towards SUVs in the LDV market could be important to support longer-term investments for stakeholders in the automotive sector, especially in cases where the need to invest in electrification has not been properly anticipated (or it has been deliberately delayed)[33], it is effectively reducing the offer of affordable vehicles on the market.
- The shift towards SUVs has therefore detrimentally impacted equity, with stronger negative consequences on part of the society subject to greater barriers to access capital, both domestically and internationally. Due to its upward pressure in new vehicle prices, and despite increases in average income that took place over the years across different geographies, this shift may also have contributed to a stagnation of the global market for new vehicles.
- The SUV shift has clear negative implications for energy efficiency improvements and CO_2 emission mitigation, as it led to sizable reduction in energy efficiency improvement in comparison with a counterfactual without this shift.
- The SUV shift is also clearly paired with increased vehicle weight and demand for materials, beyond what can become available from end-of-life management of vehicles,[34] even in replacement markets.

- Increased market shares of SUVs are also paired with negative implications for road safety, including for the most vulnerable users, exacerbating equity impacts.

- The net benefits for energy efficiency improvements and CO_2 emission mitigation from EVs.

- The EV transition will continue to require increasing extraction and processing of materials for EV batteries. Over the coming decades, material demand will not only exceed supplies that may become available from vehicle and EV battery recycling, but growing sales of electric vehicles will require rapid expansion of material demand and processing (IEA, 2023c). Electric SUVs are paired with higher energy use per km and larger battery packs, exacerbating these challenges.

- Existing evidence suggests that EV impacts on road safety are not yet clear. At the same time, key characteristics like greater weight and less noise are likely to require risk mitigation strategies to avoid negative impacts, especially but not only for vulnerable road users.

- High upfront costs of EVs also expose the EV transition to equity-related challenges, similar to the case of the SUV shift, since low-income households are subject to greater capital availability constraints and higher costs of borrowing. This is relevant both domestically and internationally, with greater exposure for low-income countries.

Contrary to the SUV shift, though, the EV transition enables access to much lower operational costs, and lower total cost of ownership, especially for highly utilized vehicles. This has positive implications for equity, as long as hurdles in overcoming higher upfront costs are addressed by policy.

Effectively addressing these key issues, while pursuing improvements across all indicators considered, requires continued policy focus on the transition towards vehicle electrification, paired with targeted policies to mitigate, and if possible, reverse, the size shift towards SUVs.

This transition is achievable with the combination of forward-looking policy and alignment of industry strategy aligned with longer term viability. Challenges related to the demand of materials and minerals for battery supplies deserve specific attention, due to their wide-ranging implications for industrial development, trade, and geopolitics. These challenges are linked with stresses regarding the availability, pace of extraction and processing of battery materials (stronger with larger EV batteries) and the need for greater diversification of the battery value chain, also for reasons related with security of supply.[35]

Policy is crucial to de-risk transformative investment choices and direct them towards a product mix capable of mitigating the negative impacts on equity, environment and road safety highlighted in this chapter. A re-envisioning of industrial priorities is needed to steer capital toward investments that provide longer term prospects for market growth and value creation.

TABLE 4: Key issues arising from the analysis of the impacts of the SUV shift and the EV transition

	CO_2 emissions	Road safety	Equity	Critical mineral demand
Electrification	green	yellow	yellow	red
SUV shift	red	red	red	yellow
Electrification and SUV shift	green	red	red	red

Note: green indicates that the impacts are minimal, or that the trend can promote better outcomes on a given metric. Yellow indicates that issues do exist, and policy makers should be aware of this, and there might be a case for regulation. Red indicates that issues should be addressed by policy, in the interest of society, the economy, and the environment.

Source: this assessment.

Policy is also crucial to handle challenges related with tensions regarding material demand and supply. In addition to scaling up supply and investing in alternative battery chemistries, demand-side measures can play an important role (Riofrancos et al., 2023). These are not limited to aspects related with the type of materials needed in EV batteries, but they also cover the effects associated with the evolution of vehicle and battery sizes. Importantly, policy measures aiming to manage the development of EV battery materials can also have positive implications for equity, especially if they are paired with other policies that enhance access to charging infrastructure.

If not paired with investments in the technology transition towards EVs by legacy OEMs, the EV transition also risks coming with a weakening of existing industrial clusters. Unless compensated by new market entrants, this can lead to overall deindustrialization. Due to impacts on jobs and their geographical location (ILO, 2021), this can also have destabilizing effects on social and economic resilience, especially for countries that currently have a strong stake in the automotive industry.[36] Policies and strategic choices for industrial development should address these deindustrialization risks (or, in countries that do not have strong automotive industry clusters, seize industrialization opportunities), while not losing focus on the need to maintain economic competitiveness.

Challenges of making affordable vehicles available on national markets could become opportunities for countries that have retained higher sales shares in the smaller market segments, as they have the possibility to leverage production already existing for the domestic market, turning it towards exports. China is particularly well positioned to gain market shares through exports for its EVs, thanks to its already strong EV production capacity – including smaller market segments – and the pervasive role that it has acquired across all stages of the battery supply chain.[37]

Due to their domestic market structure, other major global manufacturers with stronger presence in the small vehicle segments can also benefit from policy action capable of rebalancing opportunities for value creation away from SUVs and vehicles with comparatively high energy demand and emissions, as long as they continue to invest in domestic production capacities for EVs and batteries. On this basis, OEMs that are active in parts of Europe, India, Korea, Japan, and part of Latin America – all characterized by shares of smaller vehicles that remain significant – are well positioned to exploit opportunities.

Further opportunities can also arise for other emerging economies, as they could kickstart and/or strengthen nascent manufacturing industries, especially if they are supported in this effort by development or clean finance. These opportunities are not limited to LDVs, but include product diversification, e.g., with two-wheelers, and improved/strengthened informal and/or structured public transport services, due to their high rate of use and higher likelihood to lead to net savings, on a total cost of ownership basis.

Other arguments supporting the case for a reversal of the shift to SUVs come from the longer-term risk for OEMs to remain relevant with the new generation of vehicle owners. Continuing to pursue a strategy of focusing on SUVs could have important drawbacks, as young vehicle owners are often subject to capital availability constraints.[38] Maintaining a continued presence of OEMs in the smaller vehicle segments is also crucial, in high-income countries, to reduce social tensions, as it helps addressing equity-related pressures also involving dynamics that touch the second-hand vehicle market.

Industry and governments that already produce small vehicles can also seize opportunities from policy actions that redistribute value creation away from large vehicles with high energy use, emissions, and material demand profiles, to continue to compete for a role as a technology provider for the likely growing middle class in emerging markets. Competitors can leverage these same opportunities to enter in these market segments, with net overall savings for material and energy demand, emissions, and road safety. Such a strategy would leverage increases in market size for smaller cars.

Policy mechanisms specifically affecting finance – such as those started with the definition of taxonomies of activities mapping sustainability-aligned investments – are also important to contain risks related with the prioritization of near-term profits as the primary driver for investment choices. In the case of shifting to SUVs, such risks include the socialization of losses, especially relevant in the presence of climate policies that require rapid CO_2 emission reductions. These instruments are also important to support investment choices – including electrification – that are aligned with scientific evidence regarding climate- and environment-related imperatives and are therefore more likely to be aligned with sustained profitability over time and lower risk to socialize costs (with net benefits for social stability, especially in democratic political systems).

4 POLICY OPTIONS

Chapters 2 and 3 documented the relevance of the SUV shift for increases in energy use, CO_2 emissions, weight, road safety risks and vehicle prices, as well as opportunities from the EV transition to address many of these challenges, with the important exceptions of increases in weight (and demand for battery materials) and an upward pressure on vehicle prices (with equity implications, domestically and internationally).

This Chapter builds upon the trends (Chapter 2) and their implications (Chapter 3), to develop recommendations on policy actions that can support continued efforts to transition to EVs, while also managing material- and equity-related challenges. The recommendations developed draw from policy instruments already adopted or under consideration that attempt to steer the automotive market towards enhanced sustainability, while enabling economic development and preserving or enhancing equity.

This Chapter aims to offer suggestions on measures that can enable both consumers and OEMs to find added value in sustainability-aligned vehicle features, rather than in options that are detrimental to health and the environment. The focus is on instruments that orient consumer and industry choices towards technologies offering improvements in energy and resource efficiency, emission reductions, and road safety. Complementary recommendations also account for the need to ensure that this transition is inclusive and socially fair, both domestically and internationally.

These recommendations build on work developed in earlier assessments (in particular IEA, 2018, ITF, 2021b, GFEI, 2021, Khan et al., 2022, Cazzola and Santos Alfageme, 2023), integrating specific insights regarding the challenges associated with the SUV shift and the EV transition discussed in Chapters 2 and 3. Novel recommendations included here focus on policy instruments targeting vehicle weight, battery materials, and equity considerations. By addressing weight, they also aim to improve road safety.

Table 5 summarizes the policies outlined in this chapter, the actions recommended with respect to each of them, and the issues that they have the potential to address.

The importance of establishing a vision regarding the EV transition, of setting clear targets (also regarding access to charging infrastructure) and of broadening understanding of the benefits of EVs (including through pilot projects) are not discussed in detail here, as they are pre-requisites for the discussion developed in this document. The same applies to:

- Safety-related technical standards, regulations, and test procedures, to enable the proper operation, safe repair, and end-of life handling of vehicle equipment and parts (including batteries and electric motors, and also covering durability aspects), as well as charging infrastructure (including sockets and connectors).
- Energy and environment-related technical standards, regulations, and test procedures, such as those regarding the measurements of energy consumption, CO_2 and air pollutants emissions, or the assessment of their lifecycle characteristics, underpinning possibilities to develop other policies.
- Communication protocols and payment instruments allowing to perform charging operation and related economic transactions, especially important for the vehicle to infrastructure interaction.
- Technical guidelines for first respondents, necessary for new technologies to ensure safety in case of crashes.
- Workforce support needed to ensure availability of skilled labour across all the steps of the automotive, energy/electricity and battery value chains.

Alternative decarbonization options to EVs using batteries (PHEVs and BEVs), such as hydrogen (fuel cell or ICE) vehicles, biofuels and e-fuels, or offsets, are not the focus of this analysis. The reasons for this are:

- limited availability of sustainably produced biofuels, limited market deployment and high investment risks associated with options using hydrogen as energy carrier (both for vehicles and refuelling infrastructure);
- far lower energy efficiency, for all hydrogen-based options (including e-fuels), with implications on costs, making them less competitive than EVs;[39] and
- the sheer size of fossil energy demand that needs to be replaced to decarbonize road transport, requiring extremely large deployment of carbon dioxide removals, in contrast with what is deemed feasible in IPCC scenarios (IPCC, 2022).[40]

TABLE 5: Policy options, recommended actions, and the potential to address key issues

Policy	Recommendations	Potential to address				
		CO_2 abatement	Pollutant emissions	Battery materials, circularity	Road safety	Affordability, equity
Energy efficiency/CO_2/GHG standards (with footprint as modulating parameter)	Ramp up stringency; adopt footprint as modulating parameter. Implement new standards; tighten standards on higher foorprint vehicles					
Pollutant emissions standards	Ensure alignment with real-world, ramp-up stringency in countries/regions lagging behind, maintain or increase stringency in leading markets					
Complementary policies on renewable fuels, vehicle manufacturing and end-of-life	Adopt a comprehensive and coherent portfolio of policies, each targetting a clearly defined regulated entity, to ensure a life-cycle coverage					
Specific safety-related regulations for EVs and batteries	Adopt legal requirements that have been developed by the UNECE WP.29					
Vehicle trade regulations based on environmental performance	Differentiate import conditions based on vehicle powertrain/characteristics (e.g., for EVs, based on emissions, etc.)					
Urban access restrictions based on environmental performance	Differentiate access based on vehicle environmental performance					
Regulations specifically targetting highly utilised vehicles, based on environmental performance	More ambitious EV sales requirements, incentivising or mandating all-electric vkm					
Regulations on vehicle footprint	Apply a maximum LDV footprint, as well as a CAFE regulation at a smaller footprint to stimulate product diversification					
Regulations on EV battery capacity	Apply a CAFE regulation mandating a maximum battery capacity in kWh					
Additional road safety requirements on heavy vehicles	Require additional passive and active safety equipment on vehicles exceeding a given weight threshold					
Differentiated purchase/ registration taxes (including VAT) based on vehicle characteristics (including footprint and weight)	Modulate taxes factoring in weight differences (e.g., excluding larger and heavier vehicles from rebates)					
Differentiated annual taxation on vehicle ownership	Increase stringency (and taxation levels) for older vehicles, with poorer environmental performance Differentiate local taxes/charges based on vehicle powertrain/characteristics (e.g., for EVs, based on emissions, etc.)					
Differentiated import duties	Differentiate local taxes/charges based on vehicle powertrain/characteristics (e.g., for EVs, based on emissions, etc.)					
Differentiate local vehicle taxes and charges	Differentiate local taxes/charges based on vehicle powertrain/characteristis (e.g., for EVs, based on emissions, etc)					
Fuel taxation and carbon prices	Increase fuel taxes to levels commensurate with the externalities of fuel consumption, the same applies more broadly to economy-wide emissions					
Road user charges	Gradually adopt road user charges to complement fuel taxes to fund transport infrastructure and cover externalities					
Redistributive measures enabled by revenue generation from carbon pricing and road user charges	Use of revenues from taxation reforms to promote public transport and target incentives and support to low-income households and businesses					
EV charger deployment and other regulations to scale up charging availability	Mandate or incentivise the provision of a charging network sufficient to ensure autonomy on all trips without excessive battery capacity					
Sustainable finance framework for sustainable activities (including EVs and related infrastructure)	Adopt a taxonomy similar to the one put in place in the European Union to orient investments towards sustainable activities, including EVs					
Scale up development aid for sustainable activities (including EVs and related infrastructure)	Scale up multilateral funding to support an inclusive EV transition globally					

Notes: dark green indicates that the policy can be designed to directly impact or target a given issue. Light green demotes positive indirect impacts. Yellow indicates neutral effects, or that effects depend on specific circumstances. Orange stands for adverse indirect impacts. Red indicates adverse impacts.

Source: dark green indicates that the policy can be designed to directly impact, or target a given issue. Light green demotes positive indirect impacts. Yellow indicates neutral effects, or dependent on specific circumstances. Orange stands for adverse indirect impacts. Red indicates adverse impacts.

4.1 REGULATORY POLICY FRAMEWORKS ON ENERGY, ENVIRONMENT AND SAFETY

4.1.1 ENVIRONMENTAL REGULATIONS

Stabilising global temperatures and mitigating the impacts of climate change requires swift action on the reduction of greenhouse gas emissions. Addressing the health impacts of poor air quality in urban areas, across the globe, also requires swift action to reduce local pollutant emissions.

Regulations limiting emissions of greenhouse gases and local pollutants are key policy instruments aiming to achieve these goals. Regulations requiring reductions of direct emissions of CO_2 and local pollutants, with a specific focus on LDVs, have already been deployed in several countries. This is not only the case in high-income countries or groups of countries, like the European Union or the United States, but also, in low- and medium-income countries, including major economies like China and India (as summarized in Table 6).

Regulations generally tend to be technology-neutral, to enable and spur innovations available at the lowest possible cost — an exception is tailpipe air pollutant emissions standards, which are developed based on techno-economic assessments of powertrain — and fuel-specific emissions control technologies. Over the past decade, based on the very dynamic technology and market developments of EVs, many of these regulatory instruments already integrate provisions — such as incentives or targeted sales share requirements — that address the specific case of EVs. Key reasons for this lie in the effectiveness of EVs in mitigating emissions, improving energy efficiency, and enabling cost-effective access to a more diversified energy mix (including scalable forms of renewable energy) in road transport, as well as in the significant implications for industrial transformations and development.[41]

Stabilising global temperatures would require ratcheting up the ambition of regulatory requirements, and not only reaching zero direct emissions from vehicle use, but also effectively abating GHG emissions associated with the production of fuels, as well as the manufacture and maintenance of vehicles and of their support infrastructure. Given the higher weight of EVs, with repercussions on tyre wear, it is also important to ensure that pollutant emission regulations effectively account for non-exhaust emissions. However, it is important to acknowledge the possibility of net benefits on non-exhaust emissions for EVs, due to reduced particle emissions from regenerative braking. Work recently finalized by the United Nations World Forum for Harmonization of Vehicle Regulations, focused on the development of related measurement methodologies, provides a solid foundation for further policy developments in this area (UNECE, 2023a).

Adopting a holistic approach is important not only to trigger an economy-wide response to the challenge of climate change (rather than a sectorial one, which would anyway be insufficient to bring GHG emissions to net zero), but also to reduce the likelihood for regulations to lead to unintended consequences.[42] The European regulatory policy portfolio — summarized in Table 7 — provides a clear example of regulatory approaches that target discrete parts of the vehicle lifecycle, each with a clearly defined set of regulated entities, in order to ensure that the overall approach is effectively holistic.

Internationally, the UNECE World Forum for Harmonization of Vehicle Regulations established, in 2022, an informal working group on Automotive Life Cycle Assessment (UNECE, 2023b), with the aim to develop a harmonized methodology to measure GHG emissions incurred by vehicles across their lifecycles.[43] This can offer an objective, scientific and multilaterally developed basis to OEMs and parts suppliers to document performance related with GHG emissions embodied in materials and components. The harmonized approach would also ensure that consumers can take decisions accounting for the use of low-carbon options and could thereby offer a complementary set of incentives beyond national or regional policy approaches.

TABLE 6: Regulations requiring reductions in energy intensity, direct CO_2 and local pollutant emissions for new vehicles in selected markets

Country or region	Fuel economy / CO_2 / GHG and pollutant emissions standards
Argentina	*Current pollutant standards are Euro 5a.*
Australia	*Australia's pollutant emissions standards are currently at Euro 5 equivalence, are harmonised with the European standards, and differ based on gross vehicle mass.*
Brazil	*Pollutant standards are PROCONVE L8 (passenger cars), and PROCONVE L7 (LCVs).*
Canada	Fleet average GHG limits for passenger cars and light trucks currently mandate a 5% improvement per year through 2025 and are closely aligned with US standards. *Since 2015, Canada's pollutant emissions standards have been aligned with the US Federal standards.*
Chile	A new CAFE fuel economy standard will come into effect in 2024, mandating limits of 18.8 km/Lge (for PLDVs) and 18.3 km/Lge (for LCVs). *Newly registered new LDV models must meet either Euro 6b or U.S. EPA Tier 3 Bin 125 standards from September 2022, while newly registered used LDVs must comply by February 2023. By September 2024, new registrations of both new and used vehicles must comply with either Euro 6c or U.S. EPA Tier 3 Bin 70.*
China	Phase V standards set a fleet average target of 4.0 L/100 km (NEDC) by 2025, and include both a per-model standard and a CAFC standard. *China 6 (similar to Euro 6) across 16 regions; China 5 (similar to Euro 5) nationwide.*
European Union	The 2023 CO_2 emission performance standards for cars and vans require achieving CO_2 emissions reductions relative to 2021 of: 15% by 2025; 55% (cars) / 50% vans by 2030; and 100% by 2035. *The EU's current pollutant emissions standards are at Euro 6d (from January 2021). A proposal for Euro 7 emissions standards is currently under negotiation.*
India	India's current CAFE target is 113 g CO_2/km in April 2022 for new cars. *BS VI standards (based on Euro 6) apply to all LDVs from April 2020.*
Indonesia	*Current pollutant emissions standards for gasoline and diesel light-duty vehicles are Euro 4 equivalent.*
Japan	The current Top Runner program began in 2022 and runs through 2030 – targeting a 32.4% improvement in fuel consumption by 2030 compared with the 2016 fleet average. *Japan's pollutant emissions standards are equivalent in stringency to Euro 6, with testing since 2018 conducted on the Worldwide Harmonized Light Vehicles Test Procedure (WLTP).*
Korea	Adopted 2030 GHG targets require reductions of 27.8% for cars and 12% for light trucks when compared to a 2020 baseline, while 2030 fuel economy standards are 37.3% more stringent for cars and 22.7% for light trucks. Manufacturers may choose to comply with either greenhouse gas or fuel economy standards. *For pollutant emissions standards, for gasoline-fuelled vehicles, Korea adopts California's Non-Methane Organic Gases fleet average system, while diesel vehicles are subject to Euro 6 regulations.*
Mexico	Current CO_2 and fuel economy standards are based on footprint-based US standards from 2012-2016 but have not increased in stringency since that time. *A mix of U.S. Tier 1 to 2 emissions limits and Euro 3 and 4 standards has been in effect since 2004.*
New Zealand	From 2022, the Clean Vehicle Standard applies GHG emissions standards. In 2023, the standard is 145g CO_2/km for PLDVs, and 218 g CO_2/km for LCVs. These increase in stringency to 63.3 g CO_2/km and 87.2 g CO_2/km in 2027 for passenger light duty vehicles and LCVs, respectively.
Russia	*From 2016, Euro 5 standards apply to all LDVs (imports and domestic alike).*
Peru	*For pollutant emissions, from 2016, light-duty vehicles must meet either the Euro 4 or the US Tier 2 standards. In 2021, Peru established standards that require light-duty vehicles to comply with Euro 6b or U.S. Tier 3/EPA 2010 emissions limits by October 2024.*
Thailand	*LDV pollutant emissions standards since 2012 have been at Euro 4.*
United States	The December 2021 greenhouse gas (GHG) standards for light-duty vehicles revises CAFE standards to be more stringent in model years 2023-2026, with targeted temporary flexibilities to address production lead times and incentivize production of near-zero and zero-emission vehicles. These are aligned with the CAFE standards for model years 2024-2026 for cars and light trucks. Proposed multipollutant standards for light- and medium-duty vehicles for 2027-2030 are under discussion. These would regulate GHGs as well as criteria air pollutants (PM, ozone, nitrogen oxides, and carbon monoxide). *In California, Low Emission Vehicle (LEV III) standards, which apply both GHG and particulate standards become gradually stricter from 2015-2025.* *Air pollutant (criteria pollutants) are currently regulated under U.S. Tier 3 standards (which apply through 2025).*
Vietnam	*As of 2022, light-duty vehicles are regulated under the Euro 5 standard.*

Notes: Text in italics refers to emissions of local pollutants. Other text refers to energy efficiency or direct emissions of CO_2.

Sources: TransportPolicy.net (n.d.), Australian Government, n.d., SAC, 2021, European Commission, n.d., True, 2021, ICCT, 2019, ICCT, 2013, NHTSA, 2022, ARB, n.d., EPA, 2023.

TABLE 7: Complementary EU regulations aiming for a holistic approach on GHG emission reductions

Life-cycle emission phases	Processes	Regulatory requirements	Other policy tools
Vehicle design, manufacture, including material extraction and processing, and end-of-life management	Vehicle design, manufacture, including material extraction and processing, and end-of-life management	Regulation on circularity requirements for vehicle design and on management of end-of-life vehicles (proposed)	Carbon pricing (Emission Trading Scheme) Carbon Border Adjustment Mechanism Energy Efficiency Directive Effort Sharing Regulation Policies targeting economy-wide decarbonisation, including from the industry sector (e.g., steel, aluminium manufacture and recycling)
		Battery durability requirements (UN Global Technical Regulation 22, recently introduced)	
	Vehicle component design and manufacture, including material extraction and processing, and end-of-life management	EU battery regulation (recently updated)	
Energy production	Primary energy extraction	Regulation on methane emissions in the energy sector (proposed, being negotiated)	
	Energy conversion	Renewable energy directive (proposed update, close to be finalized	
		Electricity market design (proposed update, being negotiated)	
Vehicle and fuel use	Energy use during operations	Regulation on tailpipe CO_2 emissions	Vehicle taxation Fuel taxation Targeted carbon pricing for road transport

Sources: this analysis based on legal and negotiating texts in UN, 2022; European Union, 2023a; European Union, 2023b; European Commission, n.d.; European Commission, 2021, European Parliament, 2023a; European Commission, 2019, European Council, 2022, European Parliament, 2023b; and European Union, 2023c.

4.1.2 ROAD SAFETY REGULATIONS

Regulations are also applied to road vehicles to improve road safety. These span a variety of topics, including active safety (brakes, steering, tyres, electronic stability controls), passive safety (to minimize the risk and severity of injury to vehicle occupants or to other road users in case of collisions, safety belts) and other general safety-related aspects (e.g., glazing, lighting). New technical provisions and are also being developed to address the specificities of vehicle connectivity and automation (UN, 2021).

The adoption of these requirements is rooted in the need to improve the behaviour, handling, and equipment of vehicles to reduce the chance and severity of crashes. The requirements also facilitate trade by reducing divergence across markets and providing a clear regime governing liability (Pernice and Debyser, 2023).

Specific safety-related regulations address the case of EVs and battery technologies. These require continuous monitoring and updates. Key examples include the case of requirements related to thermal runaway, thermal propagation, electrolyte leakage, and safety requirements in the event of a crash. These issues are being addressed by the UN World Forum for the Harmonization of vehicle regulations (UNECE, 2023c; UNECE, 2023d; ITF, 2020b).[44]

4.1.3 USE OF REGULATIONS IN VEHICLE TRADE

A number of regulatory instruments are already used to regulate vehicle trade flows. Current practices range from full trade restrictions (e.g., for used vehicles in major manufacturing countries or markets like Brazil and India) to the absence of any restrictions whatsoever (e.g., within free-trade areas like the European Union and the North American Free Trade Agreement). The diversity of regulations was one of the key reasons behind international efforts aiming to harmonize regulatory texts (UN, 2021).

Parameters used to regulate international used vehicle trade flows typically include age and pollutant emission limits and necessitate compliance with key roadworthiness requirements, leveraging UN regulations for technical considerations.

Very few trade-related regulations integrate aspects directly linked with energy efficiency and CO_2 emissions, and particular powertrain types (including EVs). New Zealand's Clean Car Standard, which came into effect in 2023, is the first regulatory instrument that requires importers to reduce the CO_2 emissions of the vehicles entering the country (Waka Kotahi, n.d.) and it represents a best practice case globally. Vehicles are collectively required to meet a set of targets, currently set until 2027, with a growing level of stringency over time (Te Manatū Waka, n.d.). Non-compliance is subject to the payment of penalties, per vehicle and g CO_2/km, similar to regulatory requirements in place in the European Union (only applicable to new vehicles). The standard is also paired with differentiated vehicle taxation (the Clean Car Discount), as discussed in section 4.3.

4.1.4 URBAN ACCESS RESTRICTIONS

Regulatory measures exist not only at the national or supra-national level, but also at regional and municipal levels, especially in Europe (Urban Access Regulations, n.d.). Low Emission Zones (LEZs) and Zero Emission Zones (ZEZ) are the most common type of local environmental regulation applied to road vehicles. They generally restrict access to sub-categories of vehicles based on environmental performance (in some jurisdictions limiting access to EVs and other technologies with zero tailpipe CO_2 and local pollutant emissions). In some cases, they complement urban access fees, discussed in Section 4.3.4, on vehicle taxation.

4.1.5 TARGETED REGULATORY REQUIREMENTS FOR SPECIFIC USAGE PROFILES

Environmental regulations promoting energy efficiency improvements, CO_2 and local pollutant emission savings (including via the EV transition) have the strongest merit for highly utilized vehicles, given that these are the ones where upfront costs (and also emissions resulting from battery manufacturing, for EVs) can be most rapidly offset, thanks to lower operational costs, lower energy requirements per km, and (in terms of societal and environmental costs) lower GHG and pollutant emissions.[45]

Like environmental regulations, there is also a case for higher stringency on safety requirements for highly utilized vehicles, due to their more frequent presence in active traffic — which increases the likelihood of crashes.

Public procurement policies are well suited to require greater regulatory stringency by incentivizing or requiring disproportionate procurement of EVs and adoption of enhanced road safety features. This applies both in cases where public authorities subsidize the acquisition of vehicles used for shared transport services and where vehicles are directly owned by the public administration.[46]

4.2 REGULATORY CHANGES TO ADDRESS VEHICLE WEIGHT INCREASES AND EQUITY-RELATED CHALLENGES

Evidence available from Chapters 2 and 3 shows the importance of introducing or adding elements accounting for weight- and equity-related issues to existing regulatory frameworks. Doing so can effectively mitigate the negative effects of the SUV shift on energy efficiency, GHG emissions (especially for ICEVs) and material demand (especially for EVs).

4.2.1 REGULATIONS ON VEHICLE FOOTPRINT

The introduction of a cap on vehicle footprint, in absolute terms, could effectively limit vehicle size increases. A corporate-average regulatory requirement, similar to those in place for fuel economy or CO_2 emissions but having footprint as the regulated parameter, would also help reverse the SUV shift observed since 2010 and could complement a cap.

Footprint-based regulations could be better than weight-based ones, as the latter would need differentiated treatment for different powertrains (namely for EVs, due to battery weight), subject to uncertainties due to varying energy density across different battery technologies.

The cap would come with strict limitations, without flexibility mechanisms, but it would only be applicable to the largest vehicles. Sales-weighted regulatory approaches are better suited to induce fleet-wide changes, integrating flexibilities to enable compliance and leave room for product diversification.

Regulations on footprint could have positive implications for equity, as they would reduce the scope for continued size increases, thereby addressing challenges arising from the transformations occurring in automotive markets.

4.2.2 REGULATIONS ON BATTERY CAPACITY

A second new regulatory instrument, cutting across environmental and safety aspects, could be particularly well suited to ensure effective and efficient utilization of battery materials. This could also be based on a corporate-average regulatory approach, solely applied to EVs and having battery capacity as the regulated parameter. The requirement can be set to prevent or even reverse the continued tendency towards an increase in battery sizes shown in Figure 20.

Using weight as the regulated parameter could also be possible but it risks leading to limitations in the way innovation can help address material availability criticalities. This is due to the fact that some of the technologies already used to handle material availability constraints rely on battery chemistries that have lower energy densities (such as LFP or sodium-ion, rather than NMC or NCA), which is partly compensated by improved cell-to-pack architectures (as discussed in Section 3.3.2).

Importantly, this approach can also effectively integrate flexibility mechanisms (including OEM pooling), enabling continued diversification of products and strategies for different OEMs (including the possibility to meet the needs of highly utilized vehicles, such as taxis and shared cars, for which larger battery packs are justifiably required).

Equity aspects could also be indirectly targeted by this approach, as growth in battery capacities tends to be paired with greater deployment of EVs in larger vehicle segments and a cap on the fleet-average capacity can effectively promote a differentiation of the offer as well as greater diversity of different battery sizes available for any given model.

This novel regulatory approach can further offer important opportunities to introduce demand-based policies to address challenges specifically related with the surge in demand for EV battery materials accompanying the EV transition, also helping to moderate eventual supply constraints. If based on battery capacity, rather than weight, it could leave greater room for changes in chemistries to help in achieving this goal. If based on weight, it could limit the relevance of technologies that have lower gravimetric energy densities than those already in use.

Due to competition among major economies for the acquisition of battery materials,[47] this policy is likely to require international coordination to be maximally effective and viable. For this reason, international fora with specific mandates to monitor the availability and price of critical materials and to ensure continued availability at the global level, as in the case of the IEA, can play a crucial enabling role in this context.

4.2.3 OTHER REGULATORY REQUIREMENTS APPLYING SPECIFICALLY TO BATTERIES

Specific regulatory tools can also be applied to batteries, as they are key components of EVs, with major relevance for vehicle weight and evolutions in material demand. Regulatory requirements regarding extended producer responsibility can be integrated into existing legislation. These can address:

- Material traceability, solutions facilitating re-use, repurposing and recycling (including an electronic "battery passport" — a digital record on battery packs that provides data on battery characteristics, such carbon footprint, state of health, procedures for dismantling, and composition of the battery).
- End-of-life requirements (including collection targets and obligations targets for the recovery of materials) — such as those already integrated in the EU Battery Regulation (European Union, 2023b). These are particularly relevant in addressing challenges related with EV battery material demand. This is especially important for the next generation of EV batteries, as these regulatory obligations can ensure that the necessary investments to enable the recycling of battery materials can be made on time, facilitating greater reliance on recycled materials as EVs introduced now and in the near future approach the end of their useful life.

Due diligence reporting requirements — also integrated in the EU Battery Regulation — aim to address social (including protection of human rights, human health, community life, including that of indigenous peoples, the protection of children, and gender equality) and environmental (protection of the natural environment and biological diversity) consequences of industries involved in the extraction, processing, and trade of certain raw materials and secondary raw materials used for battery manufacturing. These are important for managing risks associated with EV battery supply chains, and are also being used avoid de-industrialization (a choice that needs to be accompanied by a strong focus on the need to ensure effective industrial competitiveness and the avoidance of protectionism, for reasons of economic sustainability).

These provisions are additional to other requirements on battery durability (important for the optimal use of minerals, in addition to consumer protection), which saw a major milestone being finalized in 2022, in the context of the World Forum for the Harmonization of Vehicle Regulations (UNECE, 2022). Battery durability requirements for LDVs require that EVs retain at least 80% (and 70%) of their charge for at least 5 (and 8) years or 100,000 km (160,000 km), whichever comes first, and outline how to account for "virtual range" in cases where EVs are used to provide power to electricity grids. Similar requirements are now being developed also for heavy-duty vehicles (UNECE, 2023e) and – like other UN Global Technical Regulations – offer an opportunity for a common basis for country-specific transposition.

4.2.4 CHANGES IN EXISTING ENVIRONMENTAL REGULATIONS

The use of vehicle footprint as a modulating parameter of existing regulations on specific energy consumption or direct CO_2 emissions, in combination with increasing stringency of the standards as vehicle footprint increases, offers the opportunity to effectively tighten the requirements applicable to larger vehicles (including both ICEVs and EVs).

Most regions have adopted regulations using weight (and not footprint) as a modulating parameter. Under such a framework, CO_2 emissions standards are more stringent for lighter vehicles. Vehicle light-weighting is an effective means to reduce fuel consumption, but weight-based standards fail to incentivize energy saving technologies based on weight reduction, as lower weight vehicles are subject to more stringent CO_2 emissions limits. Hence, whenever possible, switching from weight-based to footprint-based standards can help to effectively incentivize light-weighting.

Alternative approaches based on weight as the modulating parameter are possible, but they have the risk losing effectiveness in promoting the use of material substitution and light-weighting solutions as energy-saving technologies for ICEVs.

Regardless of which modulating parameter is applied, tightening requirements for larger (in the case of footprint) or heavier (weight) light-duty vehicles would have positive implications for energy and CO_2 savings, without negative equity implications (as larger vehicles tend to be sold at higher prices purchased by wealthier customers, and are therefore those with greater margins available for EV deployment, resulting in a higher share of the EV deployment cost falling on premium vehicle models).

Regulatory requirements that are focused on CO_2 emissions rather than being specifically designed for EVs can also benefit significantly from legal frameworks enabling the development of strategies based on lifecycle accounting. In Europe, a recent proposal develops harmonized rules for accounting GHG emissions of transport services (European Commission, 2023a). This can help establishing a level playing field between transport modes, which can help to more effectively allocate material demand occurring from systemic responses, not limited to shifts across light-duty vehicle segments and powertrains. Equity implications depend on the nature of the systemic response. A systemic response to emission reduction for transport services can consist of an increased reliance on smaller EVs, providing opportunities to lower electricity demand, charging infrastructure needs and battery materials requirements (ITF, 2023). Such a shift could also help address equity challenges, since smaller electric vehicles (including quadricycles, discussed in Box 3, and two- or three-wheelers) are more likely to be available at lower prices.

BOX 3:

THE CASE OF QUADRICYCLES

Electrification has been accompanied, especially in Asia and also to some degree in Europe, by increasing interest in quadricycles, four-wheeled vehicles subject to limitations on maximum weight and speed. Reasons for this interest include affordability challenges for conventional LDVs, stemming in part from the SUV shift and EV transition, recent increases in fuel prices, and opportunities for OEMs to deploy these models at lower price points compared to conventional cars. Increased reliance on quadricycles can also be part of a systemic response to the decarbonization and electrification of transport services (ITF, 2023).

The specific regulatory developments in place for lighter EVs (including quadricycles) could be an enabler of market growth: the separate (and less strict[71]) regulatory framework to which quadricycles are subject[72] has been an important feature making quadricycles attractive to OEMs, as this allowed for faster design processes, minimization of components and – for successful models – has also been paired with manufacturing cost savings, enabling quicker market deployment and shortened time to market (Robert, 2020).

Other reasons that spurred OEM interest also include opportunities to attract younger customers,[73] paired with positive repercussions related with brand loyalty (Adolf, 2022), and limited risks for these vehicles to jeopardize their main markets (as they also compete as possible alternatives to two-wheelers), also linked with restrictions in terms of segment substitution potential.[74]

To ensure that it can effectively lead to net benefits, including in terms of safety, a shift in focus from cars towards quadricycles – including electric ones – in urban areas, needs to be accompanied by adequate safety provisions (ITF, 2023). Key examples include changes in current provisions regarding the use of airbags, crash tests and other safety features (NCAP, 2016).

4.2.5 CHANGES IN EXISTING ROAD SAFETY REGULATIONS

Given their impact on weight, documented in Chapters 2 and 3, and their growing market shares, EVs — like SUVs (which also have additional changes in ground clearance) — also need stringent road safety requirements.

New Car Assessment Programmes (NCAPs) have been promoted by consumer protection organisations to enhance vehicle safety features, to integrate best practices in existing regulatory texts related with active and passive safety (Euro NCAP, 2022). They also have a track record of being an important driver of enhancements of international test procedures underpinning technical regulations on road safety (Global NCAP, 2018; Perl, 2020). The work already developed in these frameworks is particularly relevant to offering solutions to improve and expand the scope of safety regulations.

Due to its specific relevance for road safety, weight can also be considered as a criterion for the introduction of additional safety regulations and/or requirements to integrate active safety features. Considering the correlation between vehicle size, weight and price, documented in Chapter 3 and in IEA (2019a), differentiated safety requirements based on weight could also bring affordability benefits, as they could increase affordability and consumer demand for lighter vehicles ", while focusing prices increases on heavy (and anyway less affordable) market segments.

4.2.6 CHANGES IN TARGETED REGULATORY REQUIREMENTS FOR SPECIFIC USAGE PROFILES

More stringent environmental regulations (i.e., vehicle efficiency or CO_2 standards, and local pollutant emissions standards, as well as specific requirements to transition vehicles towards EVs) for highly utilized vehicles can promote efficient use of minerals for EV batteries and may also generate positive spillovers in terms of equity.

In the case of minerals, the advantage comes from the fact that EVs that are more intensively used displace more GHG emissions and oil demand each year per unit battery capacity. Examples include taxis and shared mobility services as well as municipal service and postal fleets, which are driven higher cumulative lifetime distances than private cars (Morfeldt and Johansson, 2022).[48] In the case of equity, positive spillovers are especially important in emerging economies (due to greater difficulties to overcome higher upfront costs). The reason is that a targeted policy approach, e.g., mandating accelerated EV adoption for ridesharing and taxi services or government fleets (all of which face lower cost of access to capital than low-income households and businesses) can bring more EVs to emerging economies, also making EVs more broadly available locally in the second-hand vehicle market.

Good practice examples exist in developed and emerging economies. In California, the Clean Miles Standard (Government of California, 2018) requires a progressive reduction of GHG emissions per passenger km by ridesourcing services, encouraging a faster EV transition for the highly utilized vehicles providing them.[49] In London, a mandate requiring all newly registered taxis to be zero-emission capable as of 2018 was followed shortly afterwards by a voluntary commitment from Uber to transition every car on the app in the British capital to be fully electric by 2025 (ITF, 2020a; TfL, 2016; Mayor of London, 2019; Uber, 2018).[50] In the Balkans, Tirana (Albania) gave priority to EVs, HEVs and Euro 6 vehicles to enable access to additional taxi licenses. This has led to investments by several operators to deploy EVs and to invest in charging infrastructure, starting as early as 2016, with continuously increasing EV and charging station deployment over time (EnergNETMob, 2021).

Specific regulatory requirements, raising the level of ambition for fleet electrification – including leasing companies and other fleet managers, also align well with better capacity for organizational fleet planning decisions and greater relevance of total cost of ownership and lifecycle emissions, as well as growing consideration placed on environmental, social and governance (ESG) goals, as the basis for investment decisions by fleet operators (Daina, 2023).

The differentiation of environmental regulatory requirements based on footprint as a modulating parameter (as discussed in Section 4.2.3) or safety regulations based on weight (as discussed in section 4.2.4) is also applicable, in principle, to the case of highly utilized vehicles. The rational basis for this choice lies in the faster return on the capital investment (price premium) for electric or otherwise more fuel-efficient vehicles that require greater amounts of energy for their operations and that are more frequently in traffic. More stringent regulatory requirements for larger and heavier vehicles could also make smaller and lighter vehicles comparatively more affordable, thereby reorienting consumer choices towards them.

Differentiated regulations based on weight and footprint are likely easier to implement at the local level. One example is given by footprint-specific access or parking restrictions in selected urban areas, such as central districts (ITF, 2023). This is also justified by constraints related with the limited availability of street space.[51]

4.3 VEHICLE TAXATION

4.3.1 COUNTRY-LEVEL TAXATION FRAMEWORKS

Vehicles are subject to different types of taxes and fees (or a combination of fees and subsidies, in feebates or bonus/malus schemes) applicable at the country level, generally applied at the time of purchase of vehicles (e.g., as registration or value added taxes) and/or during vehicle life (in the form of annual circulation/ownership charges or recurrent fees, possibly including parking and emissions certifications).

Vehicle taxation can be differentiated based on different possible criteria. The parameters currently used by governments as discriminants for differentiated taxation include energy efficiency, diversification, security, GHG and pollutant emissions.[52] Other discriminating parameters include engine capacity (most commonly for frameworks set up before the EV transition and the adoption of downsizing as an energy efficiency measure), power, and price[53] (Carpenter and Antich, 2022).

For ICEVs, all these discriminating criteria can have impacts on both weight and equity, as energy use, CO_2 emissions and power all tend to be correlated with weight and prices (IEA, 2019a). For EVs, the decoupling between GHG emissions and prices can lead to equity-related challenges,[54] requiring corrective redistributional measures.

Ensuring that differentiated taxation is effective in fostering progress on energy efficiency and CO_2 emissions requires that these parameters become key determinants of what defines the differentiated taxation.[55] As in the case of regulations, it is also critical that differentiated taxation takes into consideration lifecycle performance.[56]

As a general rule, registration taxes are substantially higher than circulation/ownership taxes, also because the latter have a recurrent nature. Company cars also tend to be subject to lower taxation rates than private vehicles (Harding, 2014; Carpenter and Antich, 2022).[57] This has adverse equity implications, as corporations are more able to withstand a higher tax burden on their balance sheet compared to many private households, especially in lower-income countries (Carpenter and Antich, 2022).

Vehicle registration taxes also tend to be higher in countries that do not have a vehicle manufacturing industry, generating larger revenue streams for governments than in cases of countries that are major vehicle producers (Carpenter and Antich, 2022).

The design of vehicle taxation schemes also has implications for government revenues. Revenue-neutral feebates or bonus/malus schemes are better suited, from an equity perspective, for countries with higher incomes and strong car dependency (since lower income households have fewer alternatives to car ownership to access mobility). Revenue-generating frameworks are more likely to have lower equity challenges in emerging economies,[58] especially if universal access to mobility is ensured with greater investments in public transport.

Vehicle circulation/ownership taxes are used in some countries to encourage more frequent vehicle renewal, especially when they are designed such that charges increase over time. This can be beneficial from an environmental and safety perspective, as long as vehicle performance on these metrics is improving. An important limitation of this approach, particularly in car-centric high-income countries, is that circulation taxes come with equity challenges for capital-constrained households and businesses, who often rely on second-hand cars. Similar considerations also apply for low- and medium-income countries, where car buyers also rely, to a large degree, on second-hand vehicle imports.

4.3.2 KEY EXAMPLES OF COUNTRY-WIDE DIFFERENTIATED VEHICLE REGISTRATION TAXES

The use of differentiated taxes on vehicle acquisition is currently common in most countries. This is the case for taxes applied to households (summarized for selected countries and regions in Table 8) and, increasingly, also for taxation frameworks applied to businesses (Harding, 2014; Carpenter and Antich, 2022 and European Environment Agency, 2022).

Registration taxes are most frequently applied to new vehicles or used vehicle imports. In specific cases, including France and New Zealand, they also apply to second-hand used vehicles. In New Zealand, where second hand imports are the vast majority of the newly registered vehicles, the Clean Car Discount expanded earlier rebates for BEVs and PHEVs into a revenue-neutral feebate or bonus/malus scheme (New Zealand Transport Agency, 2023). The program has unique features globally, as it applies different rebate and fee curves for new versus used vehicles (with rebates and fees for used vehicles being about half those applied to new vehicles). The pairing of this differentiated vehicle taxation with New Zealand's Clean Car Standard (discussed in Section 4.1.3) is especially interesting, as it is the only case of coherently developed regulatory and taxation mechanisms applicable to both new and second-hand imports aiming to address both CO_2 emissions and the EV transition.

TABLE 8: Vehicle taxation frameworks in selected countries and regions

Country or region	Fuel economy / CO_2 / GHG and pollutant emissions standards
ASEAN	In the Association of Southeast Asian Nations (ASEAN), Singapore adopted differentiated taxation, based on the environmental performance of vehicles, starting 2012. Differentiated vehicle taxes based on CO_2 emissions/km are also in place in Indonesia (in the form of a luxury tax that uses engine size as a discriminating parameter) and Thailand. Malaysia applies differentiated vehicle excise taxes based on engine size. The Philippines differentiates vehicle taxes based on vehicle price.
China	China applies vehicle purchase taxes, allowing reductions for qualified energy-saving vehicles and exempting EVs and fuel cell electric vehicles (FCEVs).
Europe	Taxes are differentiated based on engine power (Austria, Bulgaria, Croatia, Italy – also differentiating by powertrain type – and Spain) capacity (Belgium, Czech Republic, Hungary, Romania), CO_2 emissions/km (Cyprus, Luxembourg, and Sweden – also differentiating by powertrain type). Denmark, Finland, the Netherlands combine weight and CO_2 emissions/km as modulating parameters for vehicle taxes. France combines CO_2 emissions/km, weight (from 2022), and power. From 2023, France will also mandate a ceiling on EV manufacturing emissions for EVs to qualify for subsidies. Germany, Greece, Ireland, and Portugal combine CO_2 emissions/km and engine capacity. Latvia uses weight, engine capacity, and power. EVs and FCEVs are often exempted from or subject to taxation advantages: e.g., in Austria, Belgium, Cyprus, Czech Republic, Denmark, France, Germany, Ireland, Italy, Latvia, Luxembourg, Poland, Romania, Slovakia, Slovenia, Spain, and Sweden.
India	India applies lower tax rates for EVs and FCEVs and also differentiates tax rates between cars and SUVs, penalizing the latter.
Japan	Taxation favoured the adoption of smaller cars for a long time in Japan, where "Kei-cars" benefited from tax exemptions since their designation as the smallest vehicle segment in Japan, resulting in major contributors to the consistently high market shares of these vehicles in the country. Additionally, local policies exempt Kei-cars from the requirement that applies to all other private cars to own a "garage certificate" – a dedicated parking spot permit. However, like all cars, they are not allowed to use on-street parking overnight.
Latin America	Brazil applies vehicle registration taxes, including exemptions for EVs. Colombia has differentiated taxation based on LDV categories, with higher tax rates for more expensive vehicles and incentives for EVs. El Salvador has tax incentives for EVs (BEVs and PHEVs). Mexico applies tax rates based on vehicle prices with incentives or exemptions at the Federal and State level for EVs. Peru and Uruguay also apply tax exemptions for electric and hybrid vehicles.
United States	Vehicle registration taxes are applied at the Federal level, and so are tax credits for EVs and FCEVs. Complementary measures, including taxes and exemptions for energy saving vehicles, EVs and FCEVs are applied at the State level – e.g., via the Clean Vehicle Rebate Program in California.

Sources: NEA Singapore, 2022; ITF, 2022; PWC, 2022; electrive, 2023; ACEA, 2022; Lipscy and Schipper, 2013; Parking Reform Atlas, 2021; UNEP et al., 2020; OECD, 2020; IRS, 2023; California Sales Tax Handbook, n.d.; California ARB, n.d..

4.3.3 VEHICLE TAXATION RELATED WITH INTERNATIONAL TRADE

Trade-related taxation policies, in particular duties applied to imports, can, like production incentives, contribute to the orientation of consumers' choices and industry investments, insofar as they effectively alter product prices. Trade policies are also closely related with international taxation regimes including, in particular, rules and instruments that were developed under the framework of the World Trade Organization.[59]

The WTO framework attempts to promote open trade and avoid protectionism, while allowing for special provisions and flexibility for developing countries. It allows for the application of duties, following specific procedures. Relevant agreements include one on Subsidies and Countervailing Measures (SCM) (WTO, n.d.a) and the General Agreement on Tariffs and Trade (GATT) (WTO, n.d.b). These place constraints on the use of subsidies but do not ban them outright, except if they are contingent upon export performance or local-content requirements (Wu and Salzman, 2014). Otherwise, subsidies are permissible under WTO law as long as they do not negatively harm the trade interests of other countries, meaning that a government may take unilateral actions in domestic administrative courts against another government's subsidy if it finds that the subsidy causes or threatens material injury to an established domestic industry (Wu and Salzman, 2014).

The WTO agreements also allow for other exceptions to GATT, including the need not to discriminate between "like" products and domestic and foreign products (WTO, n.d.c and WTO, n.d.d). The most relevant in the context of vehicle trade relate with Article XX of the GATT (WTO, n.d.e). This recognizes that the protection of the environment including natural resources is a legitimate object of governments.

Automobile emission standards aiming to protect air quality and reduce GHG emissions are well suited to comply with the Article XX exception to national treatment. Precedent for this exists: in the specific case of gas guzzler taxes applied in the United States, differentiated taxation for vehicles with higher GHG emissions was also deemed in line with WTO rules (WTO, 1994). A key aspect of the alignment is the requirement that the application of conditions not differ based on the country of origin.

Trade duties regarding cars and other transport vehicles are currently applied internationally on the basis of different frameworks. These span from full exemptions from any duty, as in the case of free-trade agreements, to the application of a range of different duty rates, in other cases. Import levies differentiated based on environmental reasons also exist – e.g., South Africa (PWC, 2022) – and there are cases where specific exemptions (sometimes conditional to prices) or reductions have been applied for EVs (e.g., Argentina, Armenia, Colombia, Ecuador, Indonesia, Paraguay, Philippines, Rwanda and Thailand) (PWC, 2022; IEA, 2020; Global Trade Alert, 2022; GEF 2021; Randall, 2022; TrendsInAfrica, 2023; UNEP et al., 2020).

Recent developments regarding trade and tariffs of critical materials, batteries, and EVs are leading to significant trade-related tensions across the world. Domestic subsidies and tariffs are being formulated in consideration of prospects for continued EV market growth and also in light of the scale of the industrial transition needed to decarbonise transport and energy. Tensions are driven, above all, by the extensive use by different market players of measures supporting the scale up of EVs, automotive batteries, and related supply chains – including support schemes based on domestic content (CSIS, 2022), as these are not aligned with WTO rules. These may have strong implications on the way duties applicable to cars and other transport vehicles will develop. Key examples of controversial measures include the case of the New Energy Vehicle Subsidy Programme, which came to an end in China in 2022 but may still be complemented by supportive policies at the local level — leading to a move by the European Union to investigate further (Aizhu and Blenkinsop, 2023; European Union, 2023d) and the Inflation Reduction Act in the United States, which includes country-specific provisions (US Congress, 2022; US Treasury, 2023).

4.3.4 LOCAL VEHICLE TAXES AND CHARGES

The application of charges and taxes is also possible at the local level, and it is common practice in some cities. Measures in this category include parking and access fees (i.e., congestion or cordon pricing), limited to specific urban districts or applicable across larger urban areas. These policies often have systemic impacts capable of enhancing energy efficiency and reducing environmental impacts — e.g., by stimulating shifts in modal mixes towards non-motorized or public transport (and more recently also to shared mobility services).

In some cases, they already integrate additional incentives to support the same goals through technology shifts, as in the case of targeted exemptions or differentiated charges based on pollutant and/or CO_2 emission levels. The most iconic are probably the cases of urban access charges in place in selected cities globally, including London, Milan, Stockholm and Singapore, also intended to manage efficiently the use of scarce road space (ITF, 2021a).

Differentiated local taxes and charges based on vehicle weight and footprint are not common but pioneering initiatives are starting to arise. These are discussed in section 4.4.3.

4.4 CHANGES IN VEHICLE TAXES TO ADDRESS VEHICLE WEIGHT INCREASES AND EQUITY-RELATED CHALLENGES

4.4.1 CHANGES IN COUNTRY-LEVEL TAXATION FRAMEWORKS

Evidence available from Chapters 2 and 3 shows the importance of introducing or refining elements related with weight, footprint, material requirements and equity to the criteria already used for the determination of vehicle taxation. Doing this can be instrumental in steering consumer demand and industry investments away from the continued increase in vehicle size and weight, mitigating the negative effects of the SUV shift, managing those of EVs in areas where they face greater criticalities, and ultimately reducing risks of asset stranding from governmental action to foster climate change mitigation and sustainability.

Policies already deployed in some countries offer important examples of taxation and pricing reforms capable of better addressing challenges related with trends towards vehicle weight and size increases and electrification. They can also inform strategies to transition from incentivizing EV adoption through subsidies or preferential taxation to regulatory regimes that recognize the need to address the externalities of EVs, and to collect revenues to maintain infrastructure.

In Japan, fiscal advantages for Kei-cars[60] were deployed with the aim to limit energy use, rather than vehicle (or battery[61]) weight. This is because Japan is fully reliant on fossil energy imports, and this reliance also had negative impacts on its trade balance. However, increased consideration of battery materials as critical commodities sheds new light on the Japanese Kei-car policies: similar instruments could be worth serious consideration, especially in circumstances where the availability of battery materials is constrained and in countries that do not have access to the necessary resources, domestically or via their trade partners.

Norway, the country that is by far the global leader in transitioning to electric light-duty vehicles – at 88% market share in 2022 (IEA, 2023b) – has since 1995 levied a purchase tax on ICEV vehicles that is based on vehicle weight, CO_2 and NO_x emissions. The weight tax applies to cars above 500 kg, and increases linearly, with the tax per kg increasing above 1,200 kg and again above 1,500 kg. The CO_2 emissions tax curve increases at regular intervals as well, and vehicles with CO_2 emissions below a certain value are awarded deductions to the tax (although the minimum tax is 0; i.e., consumers do not receive a subsidy or tax rebate). Starting in 2023, Norway discontinued its exemption of electric vehicles with a sticker price exceeding NOK 500,000 (about USD 46,000) from VAT. At the same time, it added an additional fee on vehicle imports (including all EVs and used vehicles) based on weight (Toll Customs Norway, 2023). While the announced change in the tax regime led to a spike in ICEV and BEV sales in December 2022, with sales of more than 2.5 times the December 2021 volumes (Holland, 2023), longer term impacts are more likely to lead to increased product diversification for EVs, away from heavy vehicles (and batteries).

France's bonus/malus feebate scheme was revised in 2022 to levy additional taxes on heavier vehicles. Vehicles that weigh more than 1,800 kg are subject to an additional tax of EUR 10/kg, with the additional weight tax ceiling at EUR 50,000. However, BEVs, FCEVs, and PHEVs with an all-electric range higher than 50 km are exempt (Government of France, 2023). A recent proposal suggested to define an eligibility scale for the French bonus/malus (still dependent on g CO_2/km), modulated on the basis of size or weight of the vehicle, rather than based on its price, or by crossing weight and size (Robinet and Gérardin, 2022). The idea follows an earlier proposal, also aiming to support consumer demand and value creation for smaller and lighter vehicles, helping to make EVs available at lower prices, minimize CO_2 emissions compared to ICE vehicles, and also compared with the lifecycle emissions of larger EVs (Meilhan, 2019). Other benefits include the possibility to limit increases in public spending linked to incentive schemes by limiting their applicability. Further benefits are associated with lower pressure on resource extraction related with EV battery materials.

Other vehicle taxation tools that can help disincentivise the purchase of larger and heavier EVs and favour the purchase of smaller, more efficient ones, include scaling down EV purchase incentives proportionally to energy consumption (with advantages for more energy efficient EVs), and adding a purchase tax proportional to EV energy consumption.

Due to the variability of mission profiles for different vehicles, including in particular highly utilized cars and vans used in taxi and car- or ridesharing services (both of which are more likely to need large battery packs to fulfil daily driving operations), there is merit in the consideration of dedicated exceptions/rules for these use cases (conditional to effective use of vehicles for these services, e.g., by requiring minimum amount of km/year to access to tax rebates). California's Clean Miles Standard (Government of California, 2018), which requires that ridesourcing services reduce GHG emissions per passenger km, is synergistically paired with incentive programs for a shift to EVs, is an example of a policy capable of delivering CO_2 cuts at lower costs (Rajagopal and Phadke, 2019).

Regarding corporate cars, equity considerations call for existing privileges to be effectively removed (Harding, 2014; Carpenter and Antich, 2022). Especially if paired with an overall upward revision, freeing up budget for redistributional purposes,[62] corporate car taxes can also be better used to foster an alignment with sustainability objectives.[63] This may be achieved by factoring in stronger differentiations based on GHG emissions (reversing lower purchase grants for EVs in many countries), size, weight or a combination of these (integrating elements capable of addressing resource depletion and road safety concerns, while also accounting for the relevance of changes in battery chemistries to manage material criticalities), as well more stringent requirements for active road safety features and progressivity of taxation with price increases.

As corporate cars can account for large shares of new vehicle registrations — and are the majority in a high-income areas like the European Union (Carpenter and Antich, 2022), likely more than that in medium- and low-income countries — these changes can also provide a way to increase the availability of more affordable and sustainable second-hand cars, including EVs, for lower-income households and businesses.

4.4.2 CHANGES IN VEHICLE TAXATION RELATED WITH INTERNATIONAL TRADE

Decisions taken at the WTO considered that the use of differentiated taxation based on prices (and therefore also product differentiation within the automobile category), including for imports, is aligned with WTO rules, as long as the differentiation is not implemented to protect the domestic production of automobiles (WTO, 1994). The compliance of automobile emission standards aiming to protect air quality and reduce GHG emissions with WTO rules (by virtue of Article XX of the GATT) also indicates that, in principle, there are possibilities to consider other criteria allowing to address environmental challenges induced by vehicle weight increases, such as those associated with mineral availability related with EV batteries.

As in the case of other the more general considerations on trade-related taxes, developed in Section 4.3.3, the topic is the subject of significant geopolitical tensions. Part of the reason lies in export restrictions, especially in cases where these are applied to materials for which a major global supplier controls high shares of overall global extraction and processing, and which serve as key inputs for the automotive EV and battery industries, along with other strategic sectors — with key examples relating to practices applied by China, for rare earths and, more recently, graphite (Wu and Salzman, 2014, European Commission, 2023b).

This suggests that, while there is the technical possibility to make progress on changes in vehicle taxation related with international trade that could help addressing criticalities flagged in Chapter 3 (namely vehicle weight increases, mineral availability, and equity aspects), their practical viability depends upon developments in the effectiveness of processes facilitating dialogue, and on negotiations taking place at the intergovernmental level.

4.4.3 CHANGES IN LOCAL VEHICLE TAXES AND CHARGES

Taxes and charges adopted at the local level can also be tailored to specific objectives associated with challenges posed by vehicle weight increases and equity-related aspects. Higher parking fees for larger, heavier vehicles adopted in Paris and other French cities, starting in 2024, are recent prominent examples of differentiated fees based on vehicle weight, currently representing best practice globally.

Differentiated fees will first be rolled out in the four central urban districts, taking into account the vehicle size and weight, and engine type (Ville de Paris, 2023; Riposseau, 2023; Willsher, 2023; Dow, 2023 and Sergeev, 2023). EVs may be exempt from larger fees or be subject to different weight thresholds, aiming to account for higher weight for comparable size with ICEVs. Exemptions are also foreseen for large families, low-income families, and disabled drivers. Fees are expected to range from EUR 15 per month for electric vehicles to triple that for the largest and heaviest ICE SUVs. In France, Lyon has also announced the plan to adopt a similar parking fee structure from 2024, and has already proposed a fee structure that starts at EUR 15 per month for all but the largest cars with low-emissions stickers (Crit'Air vert); EUR 30 per month for ICE cars from 1000-1725 kg and HEVs from 1000-1900 kg; and EUR 45 per month for ICEVs and HEVs heavier than 1725 and 1900 kg, respectively, as well as for cars with low-emission stickers weighing more than 2200 kg (Riposseau, 2023). Grenoble is expected to adopt a similar measure in the near future.

Regarding equity-related challenges, due to the SUV shift and EV transition and the application of differentiated charges for large vehicles and ICEVs vs. EVs (but also regulatory measures limiting circulation for ICEVs, and in particular low- and zero-emission zones), recent analysis developed in France flagged the importance of targeted relief measures accompanying low-income households, especially in cases of limited access to alternative modes, and in a phase when limited volumes of second-hand EVs are available[64] (Robinet and Gérardin, 2023).

4.5 FUEL TAXATION AND CARBON PRICES

Efficient levels of taxation on fossil fuels used in transport, are crucial for discouraging the deployment of vehicles with larger weight and footprint, and also for fostering the EV transition, as shown in Chapter 2. A first priority is removing harmful and unsustainable subsidies for fossil fuels, but efficient taxation should include also other "external" costs due to environmental damage, congestion, crashes, road damage and general consumption taxes (Parry et al., 2021).[65] Taxing fossil fuels for road transport is also crucial to avoid giving a competitive advantage to carbon-intensive options, which risk locking in GHG emissions for long periods of time.

Some level of fuel taxation is already in place in most — but not all — countries, primarily in the form of excise and value added taxes.[66] Differences in existing taxation schemes across countries are influenced by the historical availability (or lack thereof) of oil resources, with lower tax rates generally applied in countries with higher oil reserves, resources and domestic production, and higher tax rates for net oil importing countries. According to the International Monetary Fund, however, under-pricing of road fuels is pervasive across many countries, with 70% of global gasoline consumption being priced, in 2021, at less than 60% of efficient levels[67], and 50% of diesel fuel being priced at less than half the efficient level (Parry et al., 2021).

Beyond taxation of transport fuels, the adoption of economy-wide carbon pricing is particularly relevant in countries that have limited availability of fossil energy. Notwithstanding challenges related to increases in fossil fuel prices due to geopolitical tensions, carbon pricing is essential to meeting objectives aligned with climate imperatives, including a global transition to net zero emissions. Carbon prices not only support shifts in consumer choices towards low- and zero-carbon technologies, but also leverage the residual demand for carbon-intensive fuels to collect government revenues, which will be crucial to financing redistributive policies during the energy transition (an aspect that has specific relevance for EVs, in transport, due to their higher upfront cost and the resulting equity challenges).

One of the best practices regarding the adoption of carbon pricing for equity-related considerations is the case of the creation of a Social Climate Fund accompanying the creation of a separate Emissions Trading System (ETS), specifically dedicated to road transport and buildings, in the European Union, with fuel distributors as regulated entities.[68] Starting in 2027, this instrument will ensure price signals pass to consumers to stimulate investments in energy efficiency and energy diversification (European Parliament, 2022 and European Council, 2022). It will also use revenues generated by the ETS — up to a maximum amount of EUR 65 billion (European Parliament, 2022 and European Council, 2022) — to support Social Climate Plans meant to address the impact of carbon pricing on vulnerable households, microenterprises and vulnerable transport users. EU Member States will be required to contribute at least to 25% of the estimated total costs of their Plans.

In Europe, the reform of the ETS (European Union, 2023e), paired with the introduction of a Carbon Border Adjustment Mechanism (CBAM) (European Union, 2023f), are also instrumental to supporting the transition of the industry sector towards technologies that are compatible with the achievement of economy-wide net zero emissions included in the Climate Law (European Union, 2021). This includes the production of key materials needed in the automotive sector, in particular aluminium and steel, as well as other materials necessary for road transport infrastructure (namely iron, steel, and cement).

4.5.1 ROAD USER CHARGES TO COMPLEMENT OR PROGRESSIVELY REPLACE FUEL TAXATION

Road user charges are a policy solution that offers the potential to make up for lost fuel-duty revenues and adequately price vehicle operations. Opting for this solution would effectively switch the tax base to distance travelled rather than energy use (ITF, 2021b; OECD, 2019b).

Distance-based charges effectively apply the ‘polluter pays’ principle, where those who produce pollution bear the costs of the damage they inflict on others or the environment. Location-specific and time-dependent distance-based charges could provide a cost-effective way to address congestion, whose costs are particularly high in urban areas and at certain times of day. Charges could also potentially be differentiated to incentivize PHEVs to drive in all-electric mode and to reflect different impacts on street space occupation and road safety risks for vehicles with different sizes, weight and safety features, helping to address other negative environmental and social externalities of road transport, in particular emissions of local air pollutants, noise and traffic crashes. Since electric vehicles have fewer negative externalities associated with pollutant and GHG emissions than conventional vehicles, user charges applying to EVs would likely be lower than for comparable ICEVs (ITF, 2021b).

The shift to road user charges is likely to be complex, since governments need to find the balance between stimulating innovation and the technology transition, while also addressing the issue of revenue shortfalls (although carbon pricing can mitigate this, at least for some time, but not without challenges, particularly in the context of increasing oil prices). Moreover, road user charges will be needed to restrain potential increases in vehicle use driven by the lower travel costs of EVs, while maintaining incentives to switch to EVs and limiting social equity impacts. This complexity calls for a gradual shift, as well as the establishment of a solid technological basis for managing the transition, along with clear communication between stakeholders (including individuals that will adopt EVs) that will be affected by the change (ITF, 2021b).

4.6 ALTERNATIVE ENERGY INFRASTRUCTURE (EV CHARGERS)

The analysis in Chapter 3 highlights the fact that increased EV sales are being accompanied by increases in battery size. This is due to preferences oriented towards long-range vehicles, especially for wealthy consumers, a choice that is likely to be exacerbated by limitations in the availability of EV charging infrastructure.

Large batteries for EVs are an inefficient use of scarce resources, especially for personal vehicles, as they are not being driven for the vast majority of the time (typically they are parked around 95% of the time). Bottlenecks limiting the availability of materials needed to manufacture batteries are exacerbated by these choices, calling for demand-side measures to mitigate these issues (Box 2). Policies that can shift sales toward smaller EVs, incentives based on actual electric vkm for early deployment, and promoting all-electric driving for PHEVs,[69] could effectively deliver more fossil fuel displacement at lower costs than a strategy promoting fewer EVs with larger batteries. Large EV batteries also increase average vehicle costs, thus limiting the EV transition, and its benefits (lower total cost of ownership) to high income households.

The value-added of long-range EVs for consumers is likely to decrease as access to EV charging infrastructure, at affordable electricity prices, is effectively developed. Governments and OEMs should therefore collaborate to speed up the development of a capillary charging infrastructure network.

The Alternative Fuels Infrastructure Regulation (AFIR) of the European Union is the first example of a regulatory instrument that requires the construction of a minimum network of charging and refuelling stations along the trans-European road network, including several urban nodes and, as national plans are also finalized, on other major roads, in each Member State (European Union, 2023g).

In addition, a wide range of technical standards and other regulatory requirements are still being negotiated at the time of writing, such as the Energy Performance of Buildings Directive. The Directive includes provisions regarding electric vehicles, grounded on the consideration that charging in relation to buildings is particularly important, since this is where electric vehicles park regularly and for long periods of time, slow charging is economical and the installation of recharging points in private spaces can provide energy storage services to the building and integration of smart charging services and system integration services in general (European Commission, 2021). Pre-cabling is to become the norm for all new buildings and buildings undergoing major renovation, and barriers to the installation of recharging points in residential buildings, ensuring a “right to plug”, need to be removed. These provisions have been reinforced in following negotiating steps with clearer references to bidirectional charging, and the role of e-bikes and e-scooters in terms of the allocation of parking space, also in non-residential buildings (European Parliament, 2023a).

Other major initiatives enabling a widespread development of EV chargers have also been undertaken, over the years, in major EV economies, including China (with major investments over the years by its State Grid Corporation) and the United States. In the case of the United States, these have significantly accelerated thanks to activities and funds disbursed by the Joint Office of Energy and Transportation, established by the Bipartisan Infrastructure Law of 2021 (US DOT, n.d.) and representing a modernized inter-agency approach, bringing together expertise from the Departments of Energy and Transport to support the deployment of zero-emission, convenient, accessible, equitable transportation infrastructure (Joint Office, n.d.).

Public support, leveraging revenues from carbon taxation and debt-driven investments for infrastructure deployment (including funds that became available in the context of Covid-19 response package following the Covid-19 pandemic) can also be effective to support private investments in EV chargers, beyond minimum regulatory requirements.[70] Public revenue has effectively been allocated for this purpose in major initiatives like the NextGenerationEU instrument (European, Commission, 2023c) in Europe and the bipartisan Infrastructure Law in the United States (DOT, n.d.). Similar considerations also apply to grid reinforcements, including with interconnectors, to enhance the reliability and the profitability of variable renewable electricity generation.

Reforms in electricity market designs — such as the one developed in the European Union (European Commission, 2023d) and previous EU reforms — are not only essential in cases where the existing structure is being challenged by geopolitical circumstances, but also helpful to enable to extract value from the effective management of EV charging, including via demand-side flexibility mechanisms (Bashar Anwar et al., 2022). This can effectively support the use of EVs and related charging infrastructure as assets providing grid services, rather than as liabilities for the electricity systems.

4.7 SUSTAINABLE FINANCE AND DEVELOPMENT AID FUNDING

Sustainable finance frameworks are important to help achieving a better alignment between the decisions taken by investors, corporations and other entities with the needs dictated by risks (including those posed to the financial system) associated with climate change, biodiversity loss and other environmental consequences of economic and industrial activities. These include instruments that ensure transparent reporting and financial disclosures of exposure to these risks. They also include frameworks that help steering investments towards low-carbon and clean solutions, thanks to the clear identification of sustainability-aligned assets.

Key instruments belonging to this category of policy tools include the Taxonomy Regulation developed in the European Union in the recent past, and a number of similar initiatives being undertaken in other geographies. These include specific references to sustainability-aligned vehicles, components/parts, including EVs, and also cover charging infrastructure.

Their development can ensure that costs of borrowing for sustainability-aligned assets is subject to lower rates of interest in comparison with other products and serve as a corrective mechanism in cases of misaligned responsibility in the socialization of costs due to environmental impacts.

Current taxonomies, when considering the automotive sector, tend to be primarily focused on tailpipe emissions of CO_2. While lifecycle accounting can be effectively accounted for by other provisions, e.g., in the energy transformation and industry sectors, existing frameworks give very limited — if any — consideration to weight-related attributes of vehicles. A better integration of these aspects can effectively address risk mitigation goals of these frameworks, in similar fashion to the case of investments in less energy intensive modes of transport with respect to passenger cars and LCVs. Financial mechanisms, including debt service reserves (where governments keep cash deposits to make interest and principal payments in case a private borrower fails to make scheduled payments), government-held subordinated debt (where a public agency agrees to take on a lower priority position for debt repayment than senior debt holders), credit insurance products for bond financing (consisting of government insurance agreeing to make bond payments in case the issuer defaults), public loans and loan guarantees (enabling act as a guarantor for the private sector to obtain a market loan with a lower interest rate), grants and co-investment are also important to complement other measures (such as advance market commitments, e.g., linked with public procurement) that help to de-risk private investments needed for the industrial transformation that accompanies the EV transition.

Other initiatives are also important to better align the needs for a technological transition and equity-related aspects. These include the development of instruments facilitating access to EVs for capital-constrained households and small businesses. One example is the micro-credit mechanism developed in France, targeting entities lacking access to credit from conventional financial institutes and including a 50% guarantee by the government (Government of France, 2021).

In the international context, initiatives favouring access to capital at lower cost are crucial to help low- and medium-income countries to seize opportunities to accelerate their transition to EVs. This can be enabled by the possibility for Multilateral Development Banks (MDBs) to borrow (and therefore also lend) and at very favourable terms, if this possibility is focused on projects characterized with a better alignment with the SDGs (Cazzola and Santos Alfageme, 2023). The development of an internationally agreed, science-based international classification system (a taxonomy, similar to the one mentioned above for the EU) is a likely prerequisite to enable this development. The integration of EVs (especially if qualified based on considerations related with intensity of use and battery size), battery material extraction (subject to other sustainability and due diligence requirements) and battery recycling facilities into such a taxonomy are all in line with the objectives to ensure a greater sustainability of the value chain, to contribute to more equitable investments for industrial development, to foster the EV transition in the Global South, and also to address weight-related challenges discussed in this report.

ANNEX: METHODOLOGICAL NOTE

This edition of the GFEI benchmarking report marks a change in the data and methodology used to obtain the results. Previous iterations of the GFEI report used model-level sales and technical characteristics for all included countries; this data was then aggregated at a country and global level to assess the progress of new vehicle specific energy consumption. This iteration of the GFEI report differs in two respects:

a. The source of core sales data changed from a provider that gives model-level (and for some countries, trim-level) data — including technical specifications such as fuel and powertrain type, vehicle weight, footprint, engine capacity, and more — to another provider that provides segment level data without detailed vehicle technical specifications, and with less granular designation of powertrains (i.e. ICE, mild hybrid, hybrid, plug-in hybrid, battery electric, and fuel cell electric).

b. In switching data providers, both the resolution and country coverage have changed. In other to ensure consistency across data sources, vehicle segment definitions were standardised, both between data sources and across countries).

This section describes three elements of the renewed methodology. It first outlines the data sources used, then describes the key data processing steps that were carried out, and concludes by explaining the new WLTP conversion factors applied.

A.1 DESCRIPTION OF DATA SOURCES

A.1.1 FUEL ECONOMY IN MAJOR CAR MARKETS (2005-2017) DATA, GFEI_0517

These are the data underpinning the GFEI Working Paper 19, published in 2019 (IEA, 2019a).

The data have varying levels of granularity, with data for most major car markets being at the model-trim level.

- Vehicle characteristics include: size (wheelbase, width, height), weight (gross weight, kerb weight), engine (displacement, power), powertrain, segment, price.
- Vehicle segments are: Small Car, Medium Car, Large Car, Small SUV, Large SUV, Light Commercial Vehicle
- Powertrains: Diesel, Petrol, LPG, CNG, Hybrid, Battery Electric, Plug-in Hybrid, Fuel Cell Electric

A.1.2 GFEI 2021 DATA, IEA_19

These are the data made publicly available on the online GFEI 2021 Data Explorer by the IEA with the 2021 version of the GFEI report (IEA, 2021a).

This dataset contains information for the same set of countries as those included in the GFEI_0517 data, and the data underlying the analysis are organized according to the same segment and powertrain categories.

The publicly available data reported in the Data Explorer are aggregated output data, not the high-resolution input data used to develop that report. This means that the results are only available at for broad categories, namely:

- fuel consumption by country, powertrain, and year
- fuel consumption by country, segment, and year
- footprint by country and year,
- weight by country and year.

A.1.3 AUTOMOTIVE SALES DATA FROM MARKLINES

Marklines is a provider of automotive industry intelligence, including sales volumes, for a wide range of countries, as shown in Table A1. Vehicle sales are categorized by Type, Segment, and Powertrain. The

TABLE A1: Country coverage by data source and regional grouping

Country	GFEI_0715	IEA_19	Marklines	EEA
Argentina	x	x	x	
Australia	x	x	x	
Belarus			x	
Brazil	x	x	x	
Canada	x	x	x	
Chile	x	x	x	
China	x	x	x	
Colombia			x	
EEA countries	x	x	x	x
Egypt	x	x	x	
India	x	x	x	
Indonesia	x	x	x	
Israel			x	
Japan	x	x	x	
Kazakhstan			x	
Korea	x	x	x	
Kuwait			x	
Malaysia	x	x	x	
Mexico	x	x	x	
Myanmar			x	
New Zealand	x	x	x	
North Macedonia			x	
Oman			x	
Pakistan			x	
Peru	x	x		
Philippines	x	x	x	
Puerto Rico			x	
Russia	x	x	x	
Saudi Arabia			x	
Singapore			x	
South Africa	x	x	x	
Switzerland	x	x	x	
Taiwan			x	
Thailand	x	x	x	
Turkey	x	x	x	
United Arab Emirates			x	
Ukraine	x	x	x	
United Kingdom	x	x	x	
United States	x	x	x	
Uruguay			X	
Uzbekistan			x	
Vietnam			x	

Note: Table A1 also provides information on data availability from other data sources used in this assessment.

data download extends from 2005 to 2022. Over this period there are varying degrees of granularity for the data within in each country. This means that for a given country, model level data might only be available for certain years and not for others. When model level data is missing, regional averages are used to fill the gaps.

A.1.4 CO_2 EMISSIONS FROM CARS AND VANS, EEA, EEA

This dataset includes registrations of new vehicles at a model level in the European Economic Area (the European Union plus Norway, Switzerland, and Iceland).

Vehicle characteristics include: size (wheelbase, width, height), weight (gross weight, kerb weight), engine (displacement, power), and powertrain. These data were downloaded from 2017 to 2022 (with the 2022 data being provisional), from the EEA data hub (EEA, 2023a; EEA, 2023b).

A.2 DESCRIPTION OF DATA PROCESSING STEPS

The aim of the data processing is to use all available datasets to provide an update to the GFEI benchmarking report, without having access to the data from the original data provider. Therefore, data processing must harmonise datasets in terms of category names, segments (and segment-specific weight and footprint), powertrains (and powertrain-specific weight and footprint), fuel economy test cycles, and geographical coverage.

This can be done by moving the analysis to the minimum common level of granularity across the available datasets. In this case, that is the "country-powertrain-segment" combination (i.e. the level of resolution provided in the Marklines dataset).

A.2.1 PREPARING MARKLINES SALES DATA

Filter Marklines sales data to remove sales that do not fall in the definition of Light Duty Vehicles (gross vehicle weight < 3,500 kg).

Harmonise the Marklines vehicle segmentation naming to what is used in the IEA_19 data, based on the matching approach shown in Table A2.

A.2.2 PREPARING IEA SPECIFIC ENERGY CONSUMPTION DATA

The IEA specific energy consumption data is only available at the aggregated level for country-powertrain-year and country-segment-year combinations. These data were combined: SEC of each country-segment combination was scaled up or down depending on the powertrain.

The powertrain scaling factors depend on the relative SEC of each powertrain (e.g., hybrid vehicles consume 20% less energy than conventional gasoline, all else being equal) and on the powertrain mix within each country-segment combination in 2019.

The GFEI_0517 data fed the information underpinning the powertrain scaling factors. The final result is a dataset of country-powertrain-segment time series of sec.

A.2.3 PREPARING EEA DATA

The specific energy consumption for each vehicle was calculated starting from the CO_2 emissions by using CO_2 emissions per unit volume for different fuels and then by converting them based on the volumetric energy density of the fuels. The final values (shown in Table A2) are consistent with the indication given by the IPCC regarding the way emissions of greenhouse gas emissions from mobile sources should be reported (IPCC, 2006).

For electric vehicles, specific energy consumption was calculated from the available data on electrical consumption stated in Wh/km. This was converted to Lge/100 km, assuming an energy content of gasoline of 9.3 kWh/Lge.

For PHEVs, the electric consumption was added the fuel consumption derived from CO_2 emission data and the electric consumption data combined through a utilisation factor, calculated according to the "best estimate" Utility Factor formula developed by Fraunhofer ISI (Fraunhofer ISI, 2021) based on the electric range of each model. When this data was not available, a default utilisation factor of 0.5 was used instead.

TABLE A2: Mapping from GFEI / IEA_19 segment to Marklines segment

GFEI Segment	Marklines Segment
Small car	A
	B
Medium car	C
Large car	D
	MPV
	E
	F
Small SUV	SUV-A
	SUV-B
	SUV-C
	SUV-D
Large SUV	SUV-E
	Pickup Truck

TABLE A3: CO_2 emissions per unit volume of different fuels

EEA fuel type	Carbon content (kg CO_2/Lge)
petrol	2.32
petrol/electric	2.32
e85	2.32
diesel	2.48
diesel/electric	2.48
ng	1.88
lpg	2.1
ng-biomethane	1.88
cng	1.88
gnl	1.88
other	2.32
Unknown	2.32

Source: in line with the IPCC guidelines on the reporting of CO_2 emissions from fuel combustion from mobile sources, considering 69.3 g CO_2/MJ, for gasoline (IPCC, 2006), and 33.5 MJ/L for gasoline.

A.2.4 MATCHING OF POWERTRAIN CATEGORIES WITH MARKLINES CATEGORIES

A list of all car models included in the EEA list was manually matched to the model names available in Marklines. This matching of information enables to assign a vehicle segment to each registration included in the EEA data.

A.2.5 JOINING SPECIFIC ENERGY CONSUMPTION, WEIGHT, AND FOOTPRINT DATA TO SALES DATA

Specific energy consumption data from IEA_19 data was merged with the relevant "segment-powertrain-country" combination of the Marklines data.

Footprint and weight data from GFEI_0517 was associated with the relevant "segment-powertrain-country" combination of the Marklines data. It was necessary to use this older dataset for footprint and weight because IEA_19 does not provide sufficient granularity.

A.2.6 IMPROVEMENTS IN ICE VEHICLE EFFICIENCY TECHNOLOGIES

A drawback of the current approach is that, except for EEA countries where model-level data on specific energy consumption is available (for 2017-2022), it is impossible to assess improvements over time within powertrain-segment groupings. This is especially important for ICE engines, where specific fuel consumption can vary significantly depending on the technology applied (turbocharging, cylinder deactivation, etc.).

The approach followed focused a survey of recent changes in specific fuel consumption in top-selling models. The top 20 selling models in the USA, China, and Japan in 2022 were identified. The fuel economy of these vehicles was matched with external sources in each market — USA (Fuel Economy Guide, 2023), Japan (MLIT, 2020), and China (MIIT, 2023).

For the above countries, the observed annual improvement for each year between 2019 and 2022 in the top 20 selling models was applied to ICE vehicles. For all other countries, a 1% per year improvement rate was assumed, a value that is in line with historical improvement rates.

A.2.7 MISMATCH BETWEEN VEHICLE FACTORY SHIPMENTS AND REGISTRATIONS IN CHINA

Light-duty vehicle volumes reported in Marklines correspond to official sales volumes reported by the China Association of Automobile Manufacturers (CAAM, 2023). CAAM data is collected from car manufacturers and represents factory shipments, and hence includes exports and excludes imports.

Since the GFEI database set seeks to compare LDVs registered in and across national and regional markets, total registrations were estimated by matching sales volumes reported in the Global EV Outlook (IEA, 2023b). The corrected volumes very closely match totals reported by CAAM, after deducting exports of ICE and new energy vehicles (NEVs include plug-in hybrid, battery electric, and fuel-cell electric vehicles).

A.3 APPLYING NEW WLTC CORRECTIONS

All specific energy consumption values in this report are defined in WLTC terms. In previous iteration of the report, theoretical conversion factors between WLTC and other drive cycles were used. This year, it was possible to use real world data on WLTC and NEDC test cycles, thus enabling a re-benchmarking of the data. The difference between NEDC and WLTC varies by fuel type and, to a lesser extent, by segment type.

Table A4 shows the zero-intercept regression values by fuel-powertrain combination and by vehicle category, where passenger cars in the EEA database corresponds to Passenger Light-Duty Vehicles (PLDVs) and Light-Commercial Vehicles are LCVs, in this report). These new conversion factors were applied to the GFEI_0517 data across all fuel-powertrain-category (PLDV/LCV) combinations, to generate updated WLTC-harmonised specific energy consumption value for each "segment-powertrain-country" timeseries.

TABLE A4: NEDC to WLTC conversion factors, based on EEA database, 2019-2022

Powertrain	Category	Ratio	Source
Diesel	LCV	1.28	EEA database analysis
Electric	LCV	1.21	JRC, 2017
Petrol	LCV	1.17	EEA analysis
Hybrid petrol	LCV	1.17	Set equal to Petrol, by assumption
Unspecified	LCV	1.17	Set equal to Petrol, by assumption
Petrol-Electric	LCV	1.19	EEA analysis
CNG	LCV	1.13	EEA analysis
LPG	LCV	1.09	EEA analysis
Flexfuel	LCV	1.00	EEA analysis
Hybrid diesel	LCV	1.28	Set equal to DIesel, by assumption
Diesel plug-in	LCV	NA	See table note
Hydrogen	LCV	1.21	JRC, 2017
Diesel	PC	1.24	EEA analysis
Electric	PC	1.283	JRC, 2017
Petrol	PC	1.19	EEA analysis
Hybrid	PC	1.19	Set equal to Petrol, by assumption
Unspecified	PC	1.19	Set equal to Petrol, by assumption
Hydrogen	PC	1.28	JRC, 2017
Petrol-Electric	PC	NA	See table note
CNG	PC	1.16	EEA analysis
LPG	PC	1.15	EEA analysis
Flexfuel	PC	1.06	EEA analysis
Hybrid diesel	PC	1.24	Set equal to Diesel, by assumption
DIESEL PLUG-IN	PC	NA	SEE TABLE NOTE
CNG	PC	1.19	EEA ANALYSIS

Note: Plug-in hybrid electric vehicles were assumed to have specific energy consumption intermediate to BEVs and HEVs, assuming a Utility Factor of 0.5. The segment, country, and year-specific updated SEC of BEVs and HEVs were used to estimate the specific energy consumption of PHEVs, so: SECPHEV = (SECBEV * UR + (1-UF) * SECHEV).

A.3.1 RE-BENCHMARKING NEDC TO WLTC CONVERSION FACTORS

From 2011 to 2021, analysts at the IEA have updated assessments of the rated specific fuel consumption of light-duty vehicles (LDVs) based on proprietary data covering nearly 90% of new LDV sales/registrations (Cuenot and Fulton, 2011, Cuenot and Körner, 2013, IEA, 2019a, and IEA, 2021a). These data were merged, cleaned and validated based on publicly available databases, reported technical specifications for various models from OEMs, and research and technical reports. To enable global comparisons across countries and major markets, conversion from regional or national test cycles to a single globally harmonized test cycle, the Worldwide harmonized Light-duty Test Cycle (WLTC), was performed on the basis of engineering-based simulation models designed to measure fuel consumption and CO_2 emissions for a variety of vehicle and technology packages and for a particular driving cycle. From 2016 to 2021, conversion factors were taken from powertrain-specific (i.e. gasoline and diesel ICE) zero intercept regressions developed by the ICCT (Kühlwein et al., 2014). These were developed based on modelling from Ricardo's Data Visualization Tool (DVT), (Meszler et al., 2013) based on MSC Easy5 (Hexagon, n.d.). Conversion factors across test cycles (CAFE, NEDC, JC08, WLTC) are reported for gasoline and diesel in Table 5.2 of the ICCT 2014 report (Kühlwein et al., 2014).

For the data update in progress, based on recent literature demonstrating that the gap between NEDC and WLTC is larger than had been initially assessed in 2014 (Tsiakmakis et al., 2017, Pavlovic et al., 2018, JRC, 2023; Dornoff et al., 2020, Dornoff, 2023), the regressions were done using actual type approval data on NEDC and WLTC test cycle CO_2 emissions performance for all light-duty vehicles registered across Europe from 2019-2022, as reported by the European Environmental Agency (EEA) and shown, for diesel and gasoline passenger cars, in Figure A4.

These ratios were determined also separately for passenger vehicles and light commercial vehicles for all basic powertrain-fuel combinations in the EEA dataset (gasoline, diesel, natural gas, lpg, gasoline-electric, diesel-electric, e85). Since direct CO_2 emissions for battery-electric and fuel-cell electric vehicles are 0 g CO_2/km, ratios for specific energy consumption as measured by NEDC versus WLTC are taken from the JRC (Tsiakmakis et al., 2017).

These results summarized in Table A5, indicate that the simulated estimate for conversion factors between NEDC and WLTC developed in 2014 were lower by a factor of 1.05 for gasoline and 1.20 for diesel LDVs.

Figure A5 points to a larger gap in Europe than elsewhere and also to larger corrections in earlier years. This is primarily due to the larger share of diesel vehicles (which are subject to a greater rebasing factor of 1.2, versus 1.05 for gasoline) in Europe than in any other markets. At a global level, the larger gap in earlier years is attributable to the greater weight of European vehicle sales in global totals.

A.4 REGIONAL AGGREGATIONS

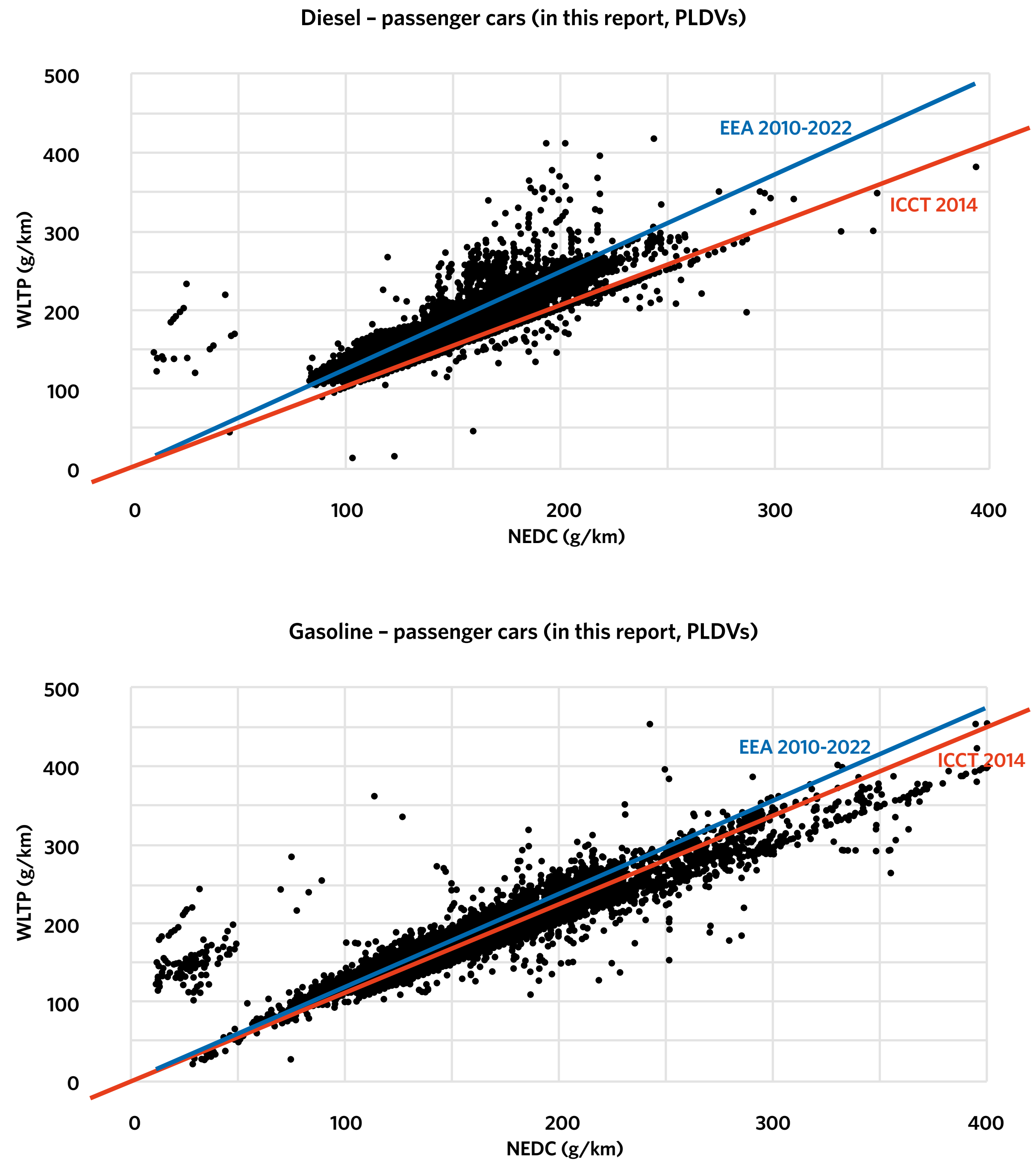
The analysis developed in Chapters 2 and 3 uses regional aggregations based on the data available at the country level, as discussed in earlier sections of this Annex. Table A6 contains information on the criteria used for the regional aggregation used for the representation of global vehicle markets in Figure 1.

TABLE A5: Regression results for gasoline and diesel conversion between NEDC and WTLC

Powertrain	NEDC to WLTC ratio ICCT 2014	NEDC to WLTC ratio update EEA data 2019-22	Ratio between 2014 and updated factor
Gasoline	1.128	1.185*	1.05
Diesel	1.0291	1.234*	1.20

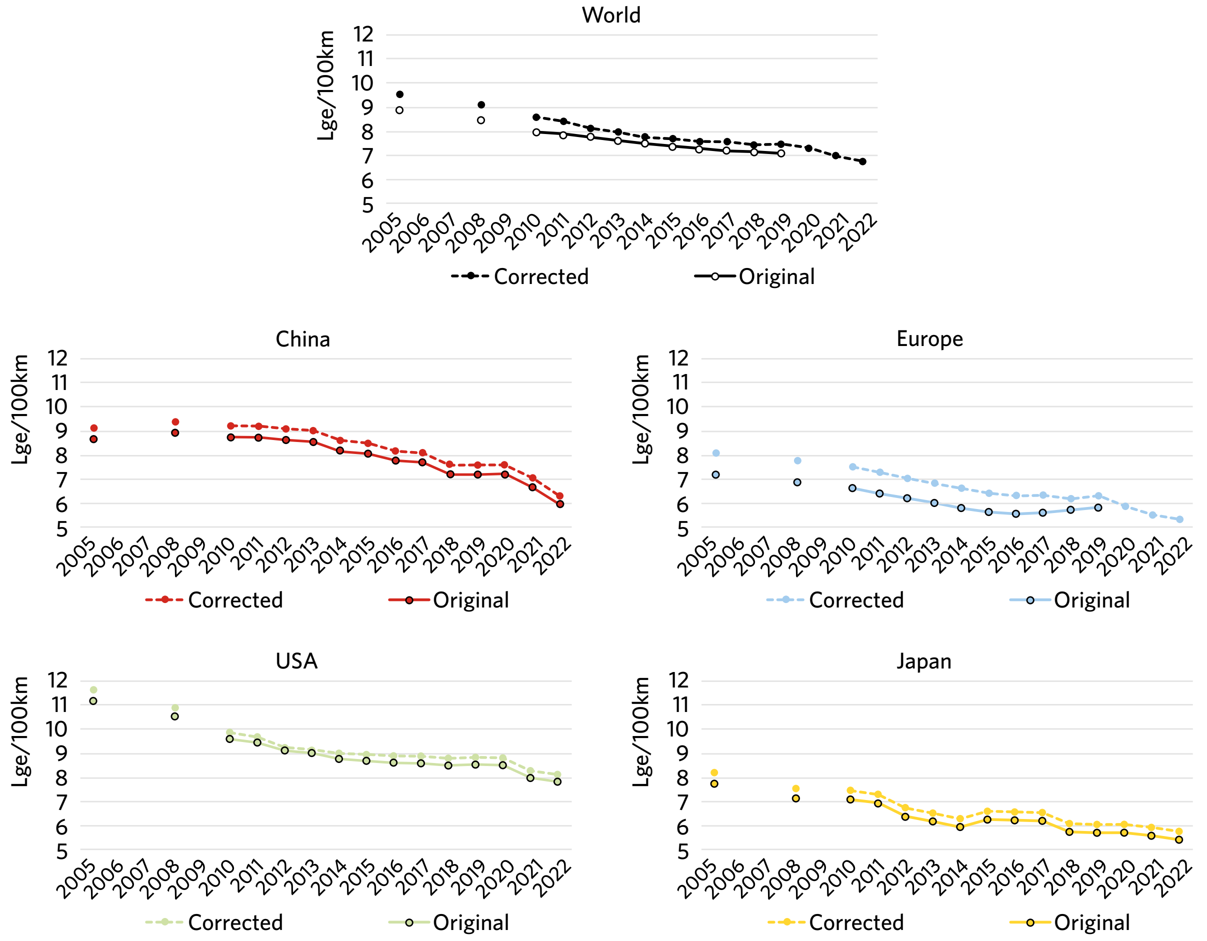
*The values reported here are for the ratio between NEDC and WLTC emissions performance (g CO_2/km) for passenger cars.

FIGURE A4: Powertrain-specific zero-intercept regressions between NEDC and WLTC, based on EEA data from 2019-2022



Note: For both gasoline- and diesel-fuelled LDVs, certain values for type-approval models seem to follow regression lines (in the case of gasoline, this regression line is quite close to the original ICCT 2014 zero-intercept factor). The authors suspect that this is due to the fact that some models were not assessed on the NEDC test cycle, but instead the NEDC values were derived by using the CO_2MPAS modelling tool (JRC, 2020).

FIGURE A5: WLTC harmonized sales-weighted average specific energy consumption for LDVs, 2005-2022



Note: Dotted lines indicate the update sales-weighted average specific energy consumption (based on the updated NEDC to WLTC rebenchmarking). Solid lines show the previously estimated specific energy consumption adopted in previous GFEI benchmarking reports.

Source: this assessment (details in the Annex) based on EEA, 2023 and Marklines data.

Key criteria used for this categorization are summarized in the following list:

- Canada and the United States are both high income, low population density countries, with comparatively low fuel taxes (based on purchasing power parities [PPP]), with domestic auto manufacturing capacity (with legacy OEMs and established and emerging EV focused ones), not reliant on major amounts of oil imports, leading to markets with very large cars and, until recently, limited EV market penetration (often focused in specific States – such as California, and/or Provinces – such as Quebec).
- The European Union, countries in the European Economic Area, Switzerland and the United Kingdom are high income, comparably high fuel tax, often with greater population density and auto manufacturing capacity (including major exporting countries, with many legacy OEMs and few EV focused ones), and generally (with targeted exceptions) net oil importers, with interest in energy diversification. They have a mixed segmentation of the car market, leaning towards larger vehicles in recent times, sizeable EV shares globally, even if still heterogeneous.

TABLE A6: Aggregation criteria for the representation of global market developments

Country	Region (code name)	Region (full name)
Argentina	11_ROW	Rest of the World
Australia	10_Australia	Australia
Belarus	11_ROW	Rest of the World
Brazil	7_BRA_MEX_MYS	Brazil, Malaysia, Mexico
Canada	1_USA_CA	North America
Chile	11_ROW	Rest of the World
China	5_China	China
Colombia	11_ROW	Rest of the World
EEA countries	2_Europe	Europe
Egypt	11_ROW	Rest of the World
India	6_India	India
Indonesia	8_INDO_GRP	Indonesia, South Africa, Thailand and Vietnam
Israel	9_MiddleEast	Middle East
Japan	4_Japan	Japan
Kazakhstan	11_ROW	Rest of the World
Korea	3_Korea	Korea
Kuwait	9_MiddleEast	Middle East
Malaysia	7_BRA_MEX_MYS	Brazil, Malaysia, Mexico
Mexico	7_BRA_MEX_MYS	Brazil, Malaysia, Mexico
Myanmar	11_ROW	Rest of the World
New Zealand	11_ROW	Rest of the World
North Macedonia	11_ROW	Rest of the World
Oman	9_MiddleEast	Middle East
Pakistan	11_ROW	Rest of the World
Peru	11_ROW	Rest of the World
Philippines	11_ROW	Rest of the World
Puerto Rico	11_ROW	Rest of the World
Russia	2_Europe	Europe
Saudi Arabia	9_MiddleEast	Middle East
Singapore	11_ROW	Rest of the World
South Africa	8_INDO_GRP	Indonesia, South Africa, Thailand and Vietnam
Switzerland	2_Europe	Europe
Taiwan	11_ROW	Rest of the World
Thailand	8_INDO_GRP	Indonesia, South Africa, Thailand and Vietnam
Turkey	11_ROW	Rest of the World
United Arab Emirates	9_MiddleEast	Middle East
Ukraine	11_ROW	Rest of the World
United Kingdom	2_Europe	Europe
United States	1_USA_CA	North America
Uruguay	11_ROW	Rest of the World
Uzbekistan	11_ROW	Rest of the World
Vietnam	8_INDO_GRP	Indonesia, South Africa, Thailand and Vietnam

- Korea and Japan are both countries with high income, high density, high PPP fuel tax, domestic auto manufacturing (and export) capacity (with legacy OEMs, some of which have strong EV ambitions, especially in Korea). Both are also oil importers, with interest in energy diversification despite limited opportunities to shift towards renewables. They have a car market segmentation similar to Europe.

- China is a major economy with medium income levels, medium/high urban density (especially in the coastal area), fairly high PPP fuel tax, with domestic auto manufacturing capacity. It is also an oil importer, with strong interest in energy diversification. Its car market is diverse, including small/medium and large cars/SVUs, reflecting the combination of an income effect that keeps vehicles smaller than in high Europe, Korea and Japan, and lower fuel prices (with an upward impact on segment shifts towards SUVs). China also have large EV shares, globally.

- India as a comparatively low income (with respect to earlier cases), medium to high population density (including some very densely populated States), high PPP fuel tax, domestic auto manufacturing capacity. It is a major oil importer, with interest in energy diversification. Its vehicles are smaller than in countries outlined earlier, due top the combination of income and fuel price effects. EV shares are still limited, most likely due to income- and affordability-related constraints and presence of legacy OEMs.

- Brazil, Malaysia and Mexico have comparatively low incomes with respect to Canada, Europe and the United States, rather low population density (despite major densely populated megacities) and medium to low PPP fuel taxes. They are auto manufacturers, and self-sufficient, if not exporters, of oil. Their vehicle segmentation is mixed, as a result of and income effect favouring smaller cars and fuel prices allowing for larger models to be more appealing. EV shares are limited, for reasons similar to those identified for India, with the additional reason of self-sufficiency for oil supplies.

- Indonesia, Thailand South Africa and Vietnam have comparatively low incomes with respect to Canada, Europe and the United States, low population density (except for major urban agglomerations), medium to low PPP fuel taxes. They have domestic car manufacturing capacity, they are net oil importers, with interest in oil diversification. Their automotive market segmentation is not strongly focused on large SUVs, due to the income effect, even if this is mitigated by medium to low fuel taxation. EV shares are limited, for reasons similar to those identified for India.

- The Middle East includes many countries with medium income, heterogeneous (and often low, outside of cities) density, low PPP fuel tax. The region is not an auto manufacturer, it is a strong oil exporter, with limited interest in oil diversification, except for climate-related risks. Vehicles in the Middle East end to be large, in line with low fuel taxation, similar to North America. EV market penetration is small, mainly paired with early moves on economic diversification.

- The rest of the World includes mainly small and rather low-income countries, with heterogeneous population densities, a tendency to apply low to medium PPP fuel tax and no major auto manufacturing capacity (Turkey being a key exception to many of these criteria). Most countries are net oil importers. Vehicle segmentation is mixed and EV shares tend to be low.

ABBREVIATIONS AND ACRONYMS

BEV	battery electric vehicle
CAFE	corporate average fuel economy
CNG	compressed natural gas
CO_2	carbon dioxide
EPA	Environmental Protection Agency
FCEV	fuel cell electric vehicle
GFEI	Global Fuel Economy Initiative
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies
HEV	hybrid electric vehicle
ICE	internal combustion engine
IEA	International Energy Agency
LCV	light commercial vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
NEDC	New European Driving Cycle
OICA	International Organisation of Motor Vehicle Manufacturers (Organisation Internationale des Constructeurs d'Automobiles)
PHEV	plug-in electric vehicle
SEC	specific energy consumption
WLTC	Worldwide Harmonized Light-Duty Vehicle Test Cycle

UNITS OF MEASURE

cm^3	cubic centimetre
g CO_2-eq	gramme of carbon dioxide equivalent
Gt	gigatonne
kg	kilogramme
km	kilometre
kW	kilowatt
kWh	kilowatt-hour
L	litre
Lge	litre of gasoline equivalent
m^2	square metre
MJ	megajoule

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ENDNOTES

1 Europe includes all member countries of the European Economic Area (EEA) plus Switzerland and the United Kingdom. North America includes the United States and Canada but excludes Mexico, as that country's vehicle market and regulatory framework both are quite different from those of United States and Canada (whose market and regulations are quite similar). For the full list of countries in each region, see the Table A6 of the appendix.

2 Data collected and reported here attempt, to the extent possible, to focus on vehicles classified as M1 in the Consolidated Resolution on the Construction of Vehicles of the United Nations (UN, 2023), considered as passenger cars and SUVs. Light commercial vehicles are classified as N1 in the same Resolution. For markets not applying these definitions (in particular the United States), passenger cars are considered as the Category 1-1 vehicle according to the Special Resolution 1 concerning the common definitions of vehicle categories, masses and dimensions (S.R.1) of the United Nations (UN, 2005). Light commercial vehicles belong to Category 2 and include vans. More specifically, they include vehicles in Classes 1 and 2 (i.e. Light Duty Vehicles) based on the classification of the Federal Highway Administration (AFDC, n.d.).

3 These affected, at once, near-term deployment of shared vehicles, vehicle lifetime and turnover rates and consumer interest. Available evidence from global reviews (such as Sprei, 2018; Adler, 2019; Tirachini, 2019; and ITF, 2020a) indicates that these may have contributed to contain the growth in personal vehicle ownership, despite remaining uncertainties.

4 North America includes the United States and Canada but excludes Mexico, as that country's vehicle market and regulatory framework both are quite different from those of United States and Canada (whose market and regulations are quite similar). Europe includes all member countries of the European Economic Area (EEA) plus Switzerland and the United Kingdom. For the full list of countries in each region, see Table A1 of the appendix.

5 Consumer prices for new cars and trucks have risen by over 20% over four years since the second half of 2020; slightly higher than the overall increase in consumer prices of 18% over the same period (Bureau of Labor Statistics, 2023).

6 Where Lge stands for litres of gasoline equivalent. Lge is used to standardise fuel consumption according to their volumetric energy content. One litre of diesel equals 1.14 litres of gasoline equivalent. As Lge measures energy, it is directly converted into kWh or MJ: considering 33.5 MJ/Lge, 44.8 MJ/kg and 3.6 MJ/kWh, 1 Lge corresponds to 9.3 kWh. This is in line with the IPCC guidelines on the reporting of CO_2 emissions from fuel combustion from mobile sources, considering 69.3 g CO_2/MJ, for gasoline (IPCC, 2006).

7 Since gasoline and diesel are a globally traded commodity, their cost of production varies little across countries. Most of the variability in fuel prices can be explained by fuel taxation and subsidy regimes.

8 European countries, Japan and Korea tend to apply high fuel taxes, which push fuel prices above USD 1.5/litre (scaled to reflect affordability using PPP). The sales-weighted average fuel consumption of light-duty vehicles sold in many of these countries are among the lowest in the world. In these countries, fuel economy regulations are also stringent. In contrast, fuel taxes in Australia, Canada and the United States are low, fuel prices are just below USD 1/litre, and the average fuel consumption of light-duty vehicles is above the global average. While high level results are also clear for developing countries, specific trends for the 2019 to 2022 developments are less homogeneous. If fuel prices, following a scale up based on purchasing power, are high, vehicle size and energy consumption in emerging markets and developing countries tend to have a similar magnitude to those observed in in Europe, Japan and Korea. If fuel prices are lower, average energy consumption in emerging markets and developing economies tends to lie in between the values in North America and those in Europe.

9 These are not included in the data shown in Figure 5, as they are the result of driving cycles that account for a range of accelerations and speeds (with the ambition to represent real-world driving) and do not yet include test procedures to fully integrate auxiliary loads.

10 Conversion factors across test cycles (CAFE, NEDC, JC08, WLTC) are reported for gasoline and diesel in Table 5.2 of the ICCT 2014 report. ICCT regressions were developed based on modelling results from Ricardo's Data Visualization Tool (DVT) (Meszler et al., 2013), itself based on MSC Easy5 (Hexagon, n.d.).

11 Data came from EEA databases of CO_2 emissions from new passenger cars (PLDVs, in the GFEI reports) and CO_2 emissions from light commercial vehicles (LCVs), using EEA final data for 2019-2021 and preliminary data for 2022.

12 The recognition of a systemic mismatch between real-world and rated NOx emissions increased regulatory pressure and reduced consumer interest in diesel vehicles. Since 2015, the stringency of pollutant emissions standards in Europe has increased markedly, especially for diesel vehicles (European Court of Auditors, 2019). The need to comply with these stricter pollutant emissions standards eroded the cost advantages of diesel cars, especially for small and medium vehicles, segments where the decline in diesel sales shares has been fastest.

13 These included a super credit multiplier for vehicles with rated emissions below 50 g CO_2/km, which was gradually phased out through 2022, as well as incentives awarded in cases where the share of zero- and low-emissions vehicles exceeds a determined benchmark.

14 As discussed in Chapter 3, Japan's designation of and preferential policies toward Kei-cars contribute to the continued resilience of the small car segment there.

15 Footprint is defined as the area defined by the four points where the tires touch the ground. It is calculated as the product of the wheelbase and the average track width of the vehicle (US DOE, 2011).

16 Intended as kerb mass, defined in international regulations as the mass of the vehicle in running order, without occupant or load, but with fuel, coolant, lubricant, toolkit and spare wheel (UN, 2023).

17 As detailed in the "Micro analysis" section of the GFEI Working Paper 17, "Wider, Taller, Heavier: Evolution of Light Duty Vehicle Size Over Generations," vehicle models within segments have also gradually grown larger (as measured by footprint and height) and heavier (as measured by kerb weight) (Cuenot, 2019).

18 Environmental impacts also depend on pollutant emissions, with consequences on air quality. In the case of SUVs, emissions of local pollutants are not discussed in a specific sub-section. The reason lies in the nature of regulatory measures regarding pollutant emissions of passenger cars and part of the LCVs, since these are set in terms of grams per km, and not per unit of energy use, meaning that – excluding (i) compliance-related aspects (which are beyond the scope of this work) (ii) powertrain shifts across ICEVs (namely, between gasoline and diesel), and (iii) increased emissions of non-tailpipe large particulate emissions (road dust, tyre wear, and brake wear) resulting from the weight increases – the SUV shift has no direct implications on variations in pollutant emissions. Regarding ICE powertrain shifts, differentiated impacts relate primarily with the evolution of sales shares and differences in regulatory requirements between spark ignition (reliant on the gasoline fuel blend) and compression ignition vehicles (reliant on diesel fuel).

19 According to a similar analysis developed by the IEA in 2021 (for the period 2010-2019), at the global scale, the segment shift eroded as much as 40% of the fuel consumption improvements that would otherwise have occurred, without the shift (IEA, 2021a).

20 Small increases in biofuel use have limited impacts on the carbon intensities of the fuels. These are neglected here.

21 In this context, small cars have the lowest consumer appeal, as car buyers in developed economies have higher purchasing power, and low fuel prices/taxes lead them to give less consideration operating costs.

22 Other reasons for this tendency towards an increase in vehicle age may include quality enhancements in vehicles, enabling them to become more durable. More recent developments in connectivity and over the air software updates – although they are not yet paired with sizable impacts at the scale of the global stock – could also strengthen this trend further, in the future.

23 Prices of second-hand cars have been heavily influenced by Covid-19 related supply chain shortages, in particular for semiconductors, resulting in lower-than-expected availability of new vehicles. These constraints contributed to a price surge in 2021 that has only been moderately easing in 2022 and 2023 (Muir, 2023; Autovista24, 2023; Manheim, 2023). Both in Europe and North America, second-hand vehicle prices are currently still well above pre-pandemic values.

24 Chapter 1 and other analyses on the EV market developments show that the increase in EV shares is currently mainly occurring in China, Europe and North America (IEA, 2023; Cazzola and Santos Alfageme, 2023).

25 Similar to the case of the SUV shift, impacts of the EV transition on emissions of local pollutants are not assessed in detail in this report. High-level indications available from other assessments point towards counteracting effects, as EVs lead to greater tyre wear and road dust, but they also come with zero emissions of local pollutants at the tailpipe. Differences in overall levels of pollutant emissions also depend on the regulatory framework and the compliance policies in place in different countries. EVs have been found in a recent OECD report to emit levels of non-exhaust emissions similar to those of well-maintained ICE vehicles in developed economies (OECD, 2020), even if non-exhaust emissions of particulate matter from tyre and brake wear were largely unregulated before the Euro 7 norm (currently being finalized). This suggests that they are likely to lead to net benefits in terms of air quality in many countries, as most of the world still applies pollutant emission norms that are less stringent than Euro 6 (i.e., the norms considered in the comparison in the OECD assessment). Importantly, analyses related with health impacts also point to lower risks for tyre wear and road dust than for exhaust emissions, due to lower content of ultra-fine particles and different chemical composition (ITF, 2021b). This also suggests that health impacts of EVs related with emissions of local air pollutants are likely to be lower than those of ICEVs.

26 The presence of the ICE and its volume is one of the key reasons why PHEVs tend to be marketed primarily in larger vehicle segments. For this reason, PHEVs may have had a relevant role, in recent years, for OEM design choices that privileged a shift to SUVs.

27 BEVs can also benefit from opportunities for radical redesign, in comparison with PHEVs.

28 Welch and Naughton, 2023 also refer to a price gap of 35% between EVs and their gasoline-fuelled counterparts.

29 This is due to lower energy efficiency of ICEV with respect to EVs and higher relevance of operational costs for ICEV drivers. Fossil fuel price volatility is partly mitigated by fuel taxation, especially in countries with higher fuel taxes. EV drivers are also affected by fossil fuel price volatility, especially in cases where electricity is still reliant on thermal generation and where electricity prices are set by the marginal electricity producer.

30 This is possible in cases showing greater demand for EVs from high-income households and from businesses subject to lower capital availability constraints. The effect may be enhanced by fossil fuel price increases.

31 It is worth noting that increased demand for batteries for stationary applications could also have positive impacts on EV battery costs, thanks to the possibility to offer greater economies of scale in battery manufacturing.

32 As long as motorization does not lead to a surge in traffic congestion. This underlines the need for a systemic approach to the management of transport decarbonization, including measures related with the development of land use and transport infrastructure, across different transport modes.

33 A shift toward EVs comes with significant costs for incumbent OEMs. These not only include research and development, but also – and probably above all – investments in new industrial facilities and re-skilling of personnel. Additional indirect costs are paired with the risk of an early dismissal of existing facilities, or parts of them. The risk of losing market share, especially in the context of policies mandating reductions in GHG emissions, due to the competitiveness of EVs in that environment, provides a strong counterbalancing force to delayed investments in the powertrain transition.

34 The greater material intensity of SUVs—and in particular steel and aluminium content—together with recovery rates of recycled materials that are even in the best cases less than one, plus the need for high-quality (and often primary) materials in certain cases (e.g., for advanced high-strength steel), means that even circular material flows would not be sufficient to supply materials for newly produced vehicles.

35 These relate with lower risks of supply disruptions in a diverse material extraction, material processing and battery manufacturing environment.

36 Vehicle and energy production, along with the construction and maintenance of the infrastructure they require, are important sources of direct and indirect employment (ILO, 2018).

37 China's vehicles exports boomed starting in mid-2020, with new passenger vehicle exports increasing from 1.6 million in 2021 to over 2.5 million in 2022, and 1.75 million in the first half of 2023 (CAAM, 2023), with 2023 volumes approaching exports of Germany and Japan, the world's two largest car exporters. Electric passenger vehicle export shares roughly match China's market shares – for instance, both were 29% in 2022 (CAAM, 2023), and most have gone to upper middle and high income countries (The Economist, 2023).

38 This argument may partially explain the interest of some of the major OEMs to enter more prominently in the L6 and L7 markets – i.e. quadricycles, based on UN definitions (UN, 2023) – with EVs, taking advantage of lower regulatory barriers. Possible drawbacks related to road safety challenges – including due to lower barriers in terms of vehicle age and license to drive, alongside minimum safety features of these lighter vehicles, and the fact that they would share the road with cars, pickups and SUVs – need to be adequately managed.

39 A focus on global areas with high renewable energy availability could enable the cost-effective production of low-carbon hydrogen and e-fuels. However, it should be noted that the required technologies, namely different approaches to direct air capture, are not yet commercialised. Moreover, the scale of fuel demand would require very significant rates of deployment of renewable energy production capacity in these global areas (Ueckerdt et al., 2021). This is subject to significant geopolitical challenges, including those of intended North–South relations, and questions of social justice, exacerbating (due to lower lifecycle energy efficiency) those already observed for the Desertec Industrial Initiative (DII), meant to bring large amounts of renewable electricity to Europe, from North Africa (Schmitt, 2018). Additional challenges, for e-fuels containing carbon, stem from the same sustainable biomass availability constraints already mentioned for biofuels (despite the possibility, through co-location of renewable or nuclear electricity and biomass supplies, to increase biofuel yields, with power-and-biomass to fuel technologies), as well as from the volumes of air that would need to be processed for large-scale direct air capture (DAC).

40 The same issue of huge volumes of air to be processed, for DAC-based carbon dioxide removal technologies, also apply for offsets, in addition to e-fuel production.

41 Regulations, for LDVs and beyond, may not only be enacted for environmental or safety reasons, but also as part of an industrial strategy, and even with protectionist objectives. However, in cases where the solutions promoted by regulatory developments are not cost-effective, this exposes economies and societies to risks, underlining the importance to maintain a focus on economic competitiveness when designing technology-specific regulatory tools.

42 Key examples exist in the case of biofuels, since increased demand for bio-based feedstocks (e.g., waste oils or lignocellulosic materials) in road transport can trigger shifts in demand in other sectors (e.g., the chemical and/or paper and pulp industries), or in the case of hydrogen, since increased demand for low-carbon electricity to produce renewable hydrogen can reduce the availability of low-carbon electricity in the grid, increasing demand for thermal (fossil-based) generation, and ultimately increasing GHG emissions, due to lower energy efficiency of hydrogen use vs. the direct use of electricity across many end-uses (where the higher efficiency of direct use of electricity is an indicator of better energy quality, especially for the combination of renewable electricity and electricity-based energy conversion appliances).

43 The working group aims to develop methodologies and standards to promote carbon intensity (CI) reductions across all stages of the automotive production (material and material recycling, parts and vehicle production), use, fuel and energy provision, and end-of-life. Said standards would both define default carbon intensity (CI) values for the purposes of regulation, and define procedures for monitoring, reporting and verification of operations that perform better (i.e. reduce CI) than the defaults, to enable such operations to be certificated and incentivized in the marketplace.

44 Similar considerations also apply to the case of hydrogen-powered vehicles, even if these are not the focus of this analysis. Key examples include hydrogen refuelling protocols, nozzles, compressed and/or liquid hydrogen leaks in confined spaces and crash exposure risks (ITF, 2020b).

45 This is also the case for life-cycle assessments across almost all global geographies, as many analyses have shown (e.g., IEA, 2019c and Bieker, 2021), largely thanks to the possibility to access, with low losses, at least in part, primary electricity from renewable energies and also thanks to lower energy conversion losses occurring in stationary thermal electricity generation facilities than in mobile ICEs.

46 Targeted adoption of higher regulatory stringency, as in the case of public procurement, can also effectively bridge the barrier of the development of different technical specifications (especially regarding safety), as these (with very few exceptions – e.g., light commercial vehicles for postal services in the United States) are developed in ways that are uniform across all LDVs, and not specific to different usage patterns.

47 Also due to their role in the context of material circularity, as the minerals become part of the vehicle stock representing an asset in the context of cross-sectoral decarbonisation, thanks to lower energy intensity in processes converting scrap metals than in processes requiring processing virgin materials.

48 More intensive use is not limited to the case of taxis and ridesourcing services, but it is also relevant for heavy duty road vehicles, like buses and trucks, as well as shared motorcycles.

49 Alongside other emission reduction approaches (e.g., reduced deadheading, increased reliance on shared services, including on-demand shuttle services operated by vans and minibuses (ITF, 2020a).

50 This was part of a comprehensive scheme that includes mandatory age limits for taxis, incentives for the early retirement of vehicles, investments for the deployment of publicly accessible electric vehicle chargers and the possibility to express preferences on their location, financial support for the installation of home chargers and discounted charging rates (ITF, 2020a; TfL, 2020).

51 An example of provisions that goes in the opposite direction, offering an opportunity to learn lessons on practices that are detrimental for the management of vehicle size and weight increase, is the case of new design guidance issued in 2022 for parking space dimensions in the United Kingdom. This proposes to increase the length (from 4.8 to 5 meters) and width (from 2.4 to 2.6 meters) of parking spaces, and claims that the principles behind these increases have global applicability (British Parking Association, 2022).

52 Differentiated taxation is rarely applied as a measure aiming to enhance road safety, instead safety is usually addressed via regulatory measures.

53 As in the case of luxury taxes.

54 Especially for EVs with high price tags. For high income countries, this is only partly mitigated by the possibility that an accelerated EV deployment, thanks to tax advantages, can have on the EV availability for low- and middle-income families, as they trickle down to the second-hand vehicle market.

55 This argument is also applicable to pollutant emissions, but only for second hand imports, as new light duty vehicles are subject to the same regulatory limits, per km driven.

56 Doing so may require technology-specific provisions (e.g., favouring more energy efficient vehicles, due to lower risks of higher emissions from fuel production). Not doing so risks providing signals that mislead investments, with negative implications for assets that are not aligned with overall sustainability requirements.

57 Moreover, specific company car taxation schemes exclude a variable component per unit of distance travelled, resulting in incentives to increase car use over other transport options (Harding, 2014). Others, excluding a fixed component (e.g., related with vehicle acquisition costs), may provide incentives to increase the size or value of the vehicle beyond what would be held if the full costs were taxed (Harding, 2014).

58 Where vehicle ownership is restricted to high-income households and businesses, generally representing a smaller fraction of the total, in comparison with high-income countries.

59 Most of the WTO agreements are the result of the 1986-94 Uruguay Round negotiations, signed at the Marrakesh ministerial meeting in April 1994 (WTO, n.d.f).

60 Kei-cars are Japan's smallest vehicle segment as defined by maximum dimension, engine displacement and power limits. They are subject to preferential taxation, parking, and other regulatory policies.

61 As Kei-car policies pre-date the EV transition by decades.

62 Tilting the tax rules alone does not guarantee a positive or even neutral environmental result if the overall estimated benefit is too far below the neutral fiscal level (Harding, 2014).

63 The socio-economic and distributional argument, together with the focus of businesses on the total cost of ownership rather than purchase prices, likely explains the lower purchase grants for EVs in many countries for corporate cars (Carpenter and Antich, 2022). Revising EV and other incentives for corporate vehicles requires redistribution of the additional governmental revenues generated from higher taxes on company cars. Negative impacts on the balance sheet of businesses can be handled through a shift in vehicle purchase decisions away from larger and more expensive vehicles towards more environmentally friendly technologies.

64 And as many of the second-hand EVs available are anyways in larger and more expensive market segments.

65 Clear prospects for low electricity costs reinforce this effect for the EV transition (Robinet and Gérardin, 2023). These are more likely in contexts with high shares of low-cost and low-carbon generation technologies, also because of the need to rationally apply taxes to address the externalities of unablated fossil energy used for electricity generation (OECD, 2019a).

66 Fuel excise duties are generally considered a very effective tax instrument to deal with negative implications of fossil fuel use on transport vehicles (Carpenter and Antich, 2022).

67 Net of energy security aspects, the efficient price per unit of a fossil fuel product includes supply costs, costs due to environmental damage (due to emissions of GHG sand local air pollutants) congestion, crashes, road damage and general consumption taxes (Parry et al., 2021).

68 The 'Fit for 55' package included a proposal (European Commission, 2021) to create a separate new Emissions Trading System (ETS) for road transport and buildings, with fuel distributors as regulated entities. The Council and the Parliament reached a provisional political agreement regarding this matter in December 2022 (European Parliament, 2022, European Council, 2022) and the final legislative text regarding this file was finalised in May 2023 (European Union, 2023).

69 Strict requirements for all-electric driving in zero emission environmental zones are important to ensure that there is greater consumer and industry focus on larger PHEV batteries (still far smaller than BEV batteries) in a transitional phase towards high shares of EVs for road transport electrification. Digital technologies, including solutions enabling geofencing, can help ensure that all-electric driving for PHEVs in these areas is effectively enforced, mobilizing PHEV owners to use electricity as external energy source. Other policies supporting increased shares of all-electric driving for PHEVs include the recent corrections of utility factors in the context of the WLTP test procedure, as well as continued on-board monitoring of driving habits on PHEVs, with respect to these indicators.

70 This includes (but is not limited to) fast chargers, which may require targeted support, also to enable better availability of low-cost electricity, given continuing challenges to ensure that they have an effective business model, possibly also in cases where they are owned by OEMs or by joint ventures (as these models may still require subsidization from revenues generated by vehicle sales).

71 For instance, requirements for quadricycles do not include airbags and are not subject to crash test requirements (NCAP, 2016, UN, 2023).

72 In the context of UN Regulations, these vehicles correspond to the L6 and L7 categories, rather than M1 for cars and N1 for light commercial vehicles.

73 In European cities, electric micro vehicles can be used by people as young as 14 (ITF, 2023).

74 The same considerations emerge from the need for alternative transport modes needed for extra-urban travel (ITF, 2023).

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