4

Transport and Energy

SLOCAT Partnership on Sustainable, Low Carbon Transport

Transport, Climate and Sustainability Global Status Report - 3rd edition

Contents

MODULE 4 4.1

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Transport Energy Sources

SLOCAT Partnership on Sustainable, Low Carbon Transport

Transport, Climate and Sustainability Global Status Report - 3rd edition

Key findings

Demand trends

- An analysis of 810 scenarios developed by the Intergovernmental Panel on Climate Change concluded that to limit global warming even to 2 degrees Celsius (°C), transport energy consumption would need to peak between 2030 and 2035 and then decrease. Scenarios compatible with a 1.5°C scenario would require earlier peaking and steeper reductions in energy use from the sector.
- In 2021, the growth in transport energy consumption rebounded somewhat (although it did not yet return to 2019 levels), indicating that the decline in 2020 was related to the COVID-19 pandemic and not to policy action in the sector.
- The Russian Federation's invasion of Ukraine in February 2022 led to fuel price spikes in the transport sector, underscoring the need to decouple transport from fossil fuel dependency. Towards the end of 2022, global cost inflation settled in the range of 5-10%.
- Improvements in engine technologies, the introduction of hybrid powertrains, and greater use of electric vehicles led to an 8.2% increase in the energy efficiency of cars and vans between 2015 and 2021. However, the increased popularity of sport utility vehicles (SUVs) and trucks poses a huge challenge to reducing energy consumption and emissions in the sector.
- In road transport, direct use of electricity is most efficient from an energy perspective, where this is technically and logistically feasible.
- The share of diesel among all oil products used in road transport increased from 39.1% to 45.5% between 2000 and 2020. This trend is driven largely by rising demand for freight transport, which is mostly diesel-powered.
- Biofuels are the largest renewable energy source in transport, accounting for 3.7% of the sector's energy consumption in 2021, up 0.8 percentage points since 2015. The main policies supporting biofuels are blending mandates set by countries.
- Hydrogen can play a role whenever direct electrification is impossible. Hydrogen is considered plausible for road transport (for use in heavy-duty vehicles for long distances) and for aviation and shipping.
- Despite the immense growth in electric vehicles over the last decade, electricity demand in road transport is still low, with electric vehicles accounting for around 1% of vehicles globally in 2022. Electric vehicles represented only 0.14% of total global electricity consumption in 2020.
- Electrification is most prominent in rail transport, accounting for 45% of the energy consumed by rail in 2021.
- Fossil fuels continue to account for the majority of electricity generation in the power sector, and thus for the majority of the electricity supplied for electric vehicles.
- More than 450,000 commercial flights used sustainable aviation fuel (SAF) in 2022, with SAF production increasing 200% compared to 2021. However, SAF still accounted for only 0.1% of all consumed aviation fuel as of 2022.

Emission trends

- Carbon dioxide (CO_2) emissions from road transport increased steadily between 2000 and 2020.
- Energy efficiency improvements and the use of renewable energy sources, mostly biofuels, helped reduce emissions from the transport sector. However, these savings continued to be outweighed by rising emissions from the overall growth in transport demand and from the modal shift towards higher-emitting forms of transport, leading to a net increase in emissions from the sector.
- The required shift to renewable energy in transport will have negative effects on employment in regions that are highly dependent on fossil fuels. Policies aimed at fostering the decarbonisation of transport will need to ensure an equitable and just transition towards more sustainable jobs. Globally, this shift is expected to result in a net gain in jobs.
- An "ambitious yet feasible" scenario from the International Council on Clean Transportation (ICCT) projects that the energy efficiency of light-duty vehicles will improve 0.75% annually between 2030 and 2050. Energy efficiency plays a major role in decarbonising the maritime and aviation sectors under this scenario.

Policy developments

- Mandatory standards for energy efficiency and for greenhouse gas emissions have proven to be effective instruments to drive efficiency and the shift to zero-emission vehicles.
- An increasing number of countries – mostly with limited or no domestic vehicle manufacturing – have established vehicle standards or other instruments to enhance the efficiency of imported vehicles.
- Fuel economy and greenhouse gas emission standards for heavy-duty vehicles are an important instrument to decarbonise the freight sector. In 2022, more than 70% of trucks sold were covered by fuel economy or vehicle efficiency regulations, although only seven countries or regions had such standards.
- Many countries have adopted vehicle labelling schemes to help consumers make informed choices by better understanding the life-cycle costs of vehicles.
- Biofuel blending mandates remain the most popular measure for increasing renewable energy in transport, with at least 56 countries and the European Union having established some form of obligation by the end of 2022.
- As of the end of 2022, at least six countries mentioned biofuel blending in their updated Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement, with policy implementation yet to come.
- In aviation, some countries are considering biofuel blending mandates for sustainable aviation fuel.

Photo credits: Marc A. Hermann/MTA

Overview

Fossil fuels continue to be the dominant energy source in the transport sector, determining trends for the sector's overall contributions to carbon dioxide (CO_2) emissions and air pollution. Solutions that aim to "Avoid" transport activity and to "Shift" to more efficient modes will help reduce overall energy demand, while at the same time providing broader sustainability benefits. However, for full decarbonisation, additional "Improve" measures are required to increase the energy efficiency of vehicles and reduce overall energy demand, and to replace fossil fuels with renewable energy alternatives to reduce the carbon intensity of energy use.

The fossil fuels used in transport emit large amounts of fine particulate matter, black carbon and other pollutants. In 2019, outdoor air pollution related in part to transport activity contributed to an estimated 4.2 million premature deaths.[1] This has motivated many countries to introduce fuel quality and emission standards for air pollutants and to increasingly supplement these with policies such as fuel economy and CO_2 emission standards, energy labelling schemes and differentiated taxation.

Energy use in transport must rapidly transition to renewable energy sources, including biofuels, biogas, hydrogen, synthetic fuels and renewable electricity.[2] Policies to scale up renewable fuels include biofuel blending mandates and incentives for alternative powertrains that would support the use of renewable electricity and fuels. Some renewable fuels – such as liquid biofuels, synthetic fuels and upgraded biomethane – can be used in conventional internal combustion engines with small adjustments. Railways are already significantly electrified, allowing for a quick uptake of renewables. Other sub-sectors require changes in vehicle technology, such as battery electric and fuel cell electric vehicles (*see Section 4.2 Vehicle Technologies*).

Despite the rapid increase in electric vehicles and renewable power globally, as well as steady increases in biofuels, fossil fuels continued to account for nearly all (96%) of the energy used in transport in 2021 – a share that has barely changed over the past decade, due mainly to rising transport demand.[3] Electric vehicle targets do not automatically lead to the uptake of renewable energy, unless they are coupled with specific mandates. Electric vehicles accounted for around 1% of vehicles globally in 2022, while renewable energy supplied just over one-quarter of global electricity demand.[4] Sustainable aviation fuel (SAF) accounted for less than 0.1% of all aviation fuels consumed in 2022.[5]

These trends underscore the importance of prioritising measures to reduce overall transport demand and to shift to more sustainable modes, which can lead to greater emission reduction and broader sustainability benefits; it is also critical that the electricity used for electric vehicles is generated from renewable sources.[6]

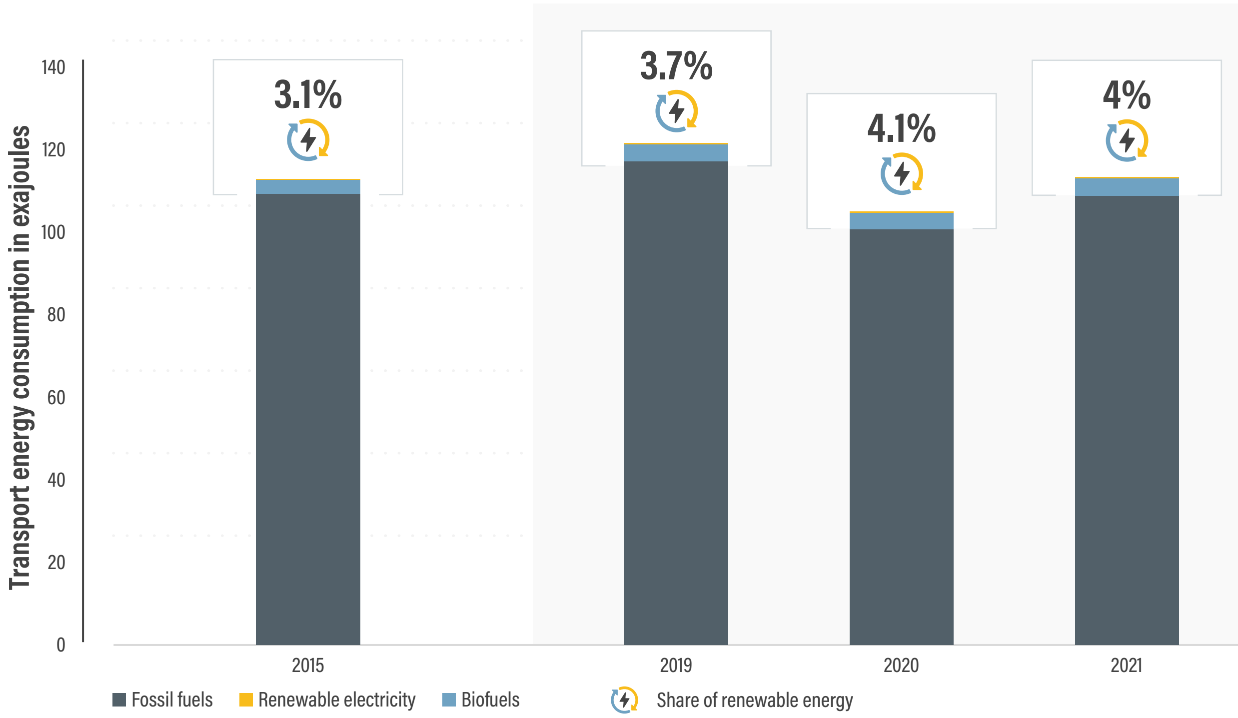
Demand trends

Several key trends, some of them contradictory, are driving greater energy consumption in transport. On the one hand, energy demand has declined due to the continuous increase in motor and vehicle efficiency and to greater use of electric vehicles (*see Section 4.2 Vehicle Technologies*). At the same time, however, energy demand has increased as both vehicle size and mass have grown (especially with the rising popularity of sport utility vehicles, SUVs), and as passenger and freight transport activity has risen overall (*see Section 1.1 Transport in Support of 1.5°C and the SDGs*).

The net growth in energy demand highlights the need to enhance efforts to rapidly improve vehicle efficiency, including by reducing vehicle weight and shifting to renewable energy sources to decarbonise the transport sector. In line with the Paris Agreement, energy demand must peak soon and then decrease rapidly. **An analysis of 810 scenarios developed by the Intergovernmental Panel on Climate Change concluded that to limit global warming even to 2 degrees Celsius (°C), transport energy consumption would need to peak between 2030 and 2035 and then decrease.**[7] **Scenarios compatible with a 1.5°C scenario would require earlier peaking and steeper reductions in energy use from the sector.**[8]

FIGURE 1 Energy consumption in transport, by energy source, 2015, 2019 to 2021

Source: See endnote 11 for this section.



In 2021, the growth in transport energy use rebounded somewhat (although it did not yet return to 2019 levels), indicating that the decline in 2020 was related to the COVID-19 pandemic and not to policy action in the sector.[9] Fossil fuels continued to dominate the sector, supplying 96% of transport energy consumption in 2020 and 2021, whereas biofuels supplied 3.7% and renewable electricity 0.35%.[10] Due mainly to the overall increase in transport demand, the share of renewables in transport remained low at 4% in 2021, up just 0.9 percentage points from 2015 (see Figure 1).[11]

The Russian Federation's invasion of Ukraine in February 2022 led to fuel price spikes in the transport sector, underscoring the need to decouple transport from fossil fuel dependency.[12] **Towards the end of 2022, global cost inflation settled in the range of 5-10%.**[13] Global oil demand and production remained relatively stable during the year, and the price of oil and subsequently transport fuels returned to mid-2021 levels by the end of 2022.[14] In some countries, pre-tax fuel prices for end users were twice as high in June 2022 as in July 2021.[15] The conflict also shifted trade for Russian oil from Europe and North America to India, China, and Türkiye, leading to a drop in container activity; however, lower trade volumes in bunker fuels were partly offset by longer transport routes (*see Section 3.8 Shipping*).[16]

Improvements in engine technologies, the introduction of hybrid powertrains and greater use of electric vehicles led to an 8.2% increase in the energy efficiency of cars and vans between 2015 and 2021.[17] The average specific fuel consumption (fuel use per 100 kilometres) has been declining (see Figure 2).[18] These improvements have been slowed by a trend towards increasing vehicle size and weight.[19] **In particular, the increased popularity of SUVs and trucks poses a huge challenge to reducing energy consumption and emissions in the sector.**[20] (*See Section 3.6 Road Transport and Section 4.2 Vehicle Technologies.*)

In road transport, direct use of electricity is most efficient from an energy perspective, where this is technically and logistically feasible. For road vehicles, the future renewable electricity demand will depend greatly on the vehicle propulsion technology used (see Table 1).[21] Battery electric vehicles are at least twice as efficient in terms of energy needed than fuel cell electric vehicles.[22] (*See also Section 4.2 Vehicle Technologies.*)

The share of diesel among all oil products used in road transport increased from 39.1% to 45.5% between 2000 and 2020 (see Figure 3).[23] **This trend is driven largely by rising demand for freight transport, which is mostly diesel-powered.** If fossil fuel-powered road freight continued, this

FIGURE 2 Specific fuel consumption of cars and vans versus sales shares of electric cars and sport utility vehicles, 2015-2021

Source: See endnote 18 for this section.

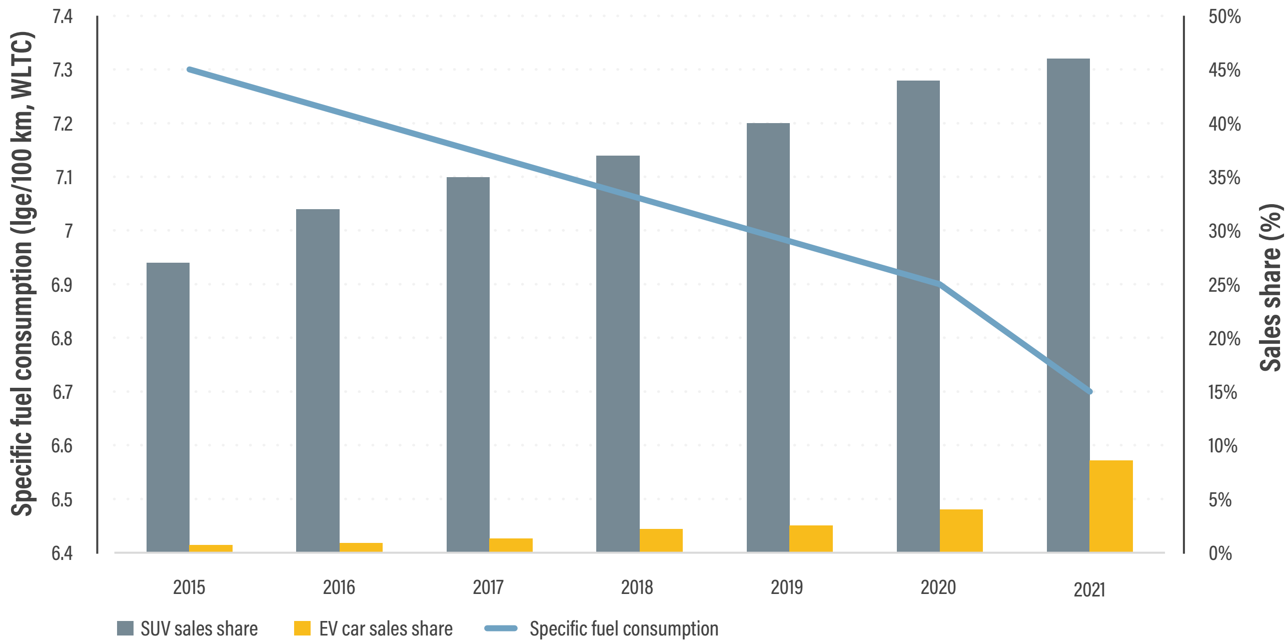


TABLE 1. Electricity requirements of different vehicle propulsion technologies

Source: See endnote 21 for this section.

Propulsion technology	Energy to generate 1 megajoule (MJ) of traction power
Battery electric vehicles	1.7 MJ
Fuel cell electric vehicles using liquid hydrogen	4.6 MJ
Synthetic fuels based on renewable electricity	7.7 MJ

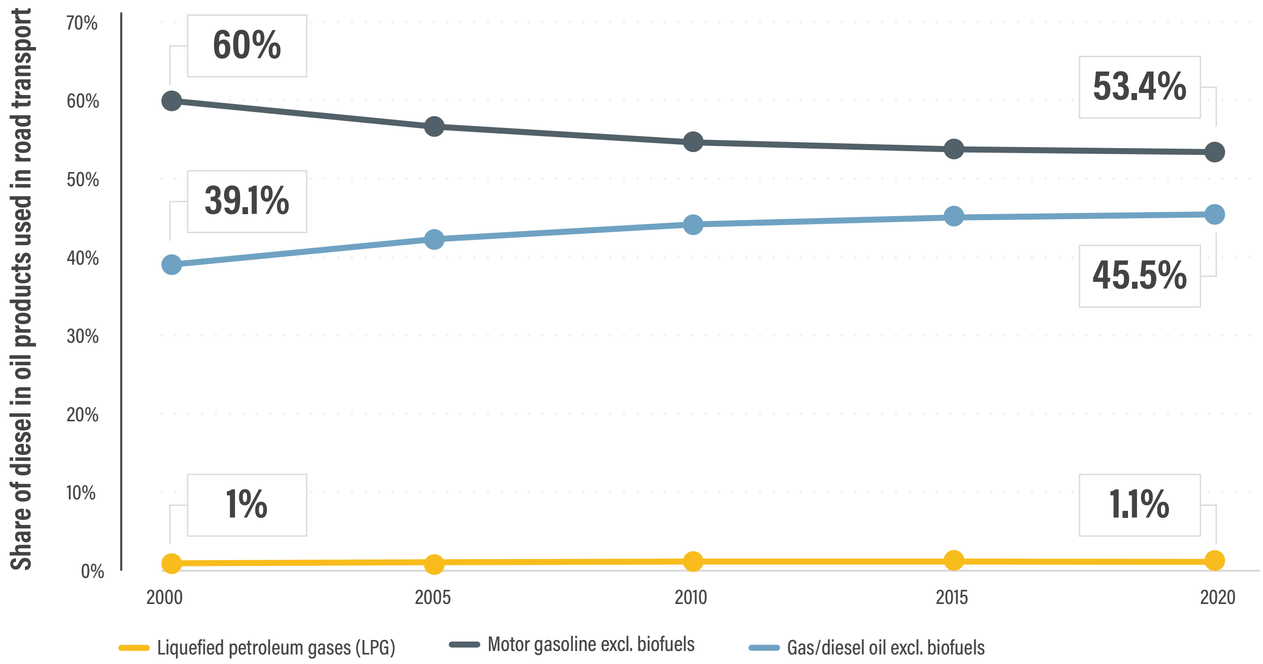
will influence the future demand for biofuels. Meanwhile, in the European Union (EU), the share of new passenger cars that run on diesel fell from 27.9% in 2020 to 19.6% in 2021.[24]

The share of natural gas used in transport increased from 3.6% to 4.5% between 2015 and 2021.[25] Natural gas consumption for trucks and buses remained stable over this period.[26] However, the number of passenger vehicle fleets running on compressed natural gas (CNG) has increased (especially in India, which has the world's largest CNG vehicle fleet), due to the rapid expansion of fuelling infrastructure and to incentive programmes for CNG vehicle purchases and retrofits.[27]

Biofuels are the largest renewable energy source in transport, accounting for 3.7% of the sector's energy consumption in 2021, up 0.8 percentage points since 2015.[28] The main policies supporting biofuels are blending mandates set by countries.[29] Biofuel growth is driven mainly

FIGURE 3 Shares of oil products used in road transport, by fuel type, 2000-2020

Source: See endnote 23 for this section.



by increased use of biodiesel, particularly fatty acid methyl ester (FAME), the dominant biodiesel type, which grew 52% between 2015 and 2021.[30] Production volumes of advanced renewable diesel in the form of hydrogenated vegetable oil (HVO) and hydroprocessed esters and fatty acids (HEFA) remain low but have grown the fastest among all biofuels, up 160% between 2015 and 2021 (see Figure 4).[31]

Whereas ethanol production fell during the COVID-19 pandemic as overall passenger transport declined, biodiesel growth continued almost unhampered, since freight activity was much less affected, with activity levels (in tonne-kilometres) remaining almost constant. In addition, an increasing number of companies (for example, in the United Kingdom), relied on **biogas** for road freight, although at a much smaller scale.[32]

Hydrogen can play a role whenever direct electrification is impossible.[33] **Hydrogen is considered plausible for road transport (for use in heavy-duty vehicles for long distances) and for aviation and shipping.**[34] Although fuel cell electric vehicles are less efficient than battery electric vehicles, they could be an option for reducing emissions from heavy-duty vehicles in the medium term.[35] However, most fuel cell vehicles (82%) were light-duty vehicles as of 2021.[36] In addition, less than 1% of global hydrogen production that year was low emission (so-called green or renewable hydrogen), while the majority was sourced from fossil fuels (grey hydrogen).[37] As of 2020, green hydrogen was at least three times more expensive to produce than grey hydrogen.[38]

Despite the immense growth in electric vehicles over the last decade, electricity demand in road transport is still low, with electric vehicles accounting for around 1% of vehicles globally in 2022 (*see Section 4.2 Vehicle Technologies*).[39] **Electric vehicles represented only 0.14% of total global electricity consumption in 2020** (see Figure 5).[40] However, demand for electricity for road vehicles increased 730% between 2015 and 2021, with most of this growth in China.[41]

Electrification is most prominent in rail transport, accounting for 45% of the energy consumed by rail in 2021.[42] Together with the small share of biodiesel used in rail transport, this resulted in a renewable energy share for rail in 2021 of 12.2%, the highest in the transport sector.[43] In aviation, the use of direct electric propulsion is so far limited to smaller aircraft and shorter distances.[44] In shipping, electrification is used only for shorter distances (such as in ferries and small vessels) or in diesel-electricity hybrid systems (*see Section 3.8 Shipping*).[45]

Fossil fuels continue to account for the majority of electricity generation in the power sector, and thus for the majority of the electricity supplied for electric vehicles.[46] The share

FIGURE 4 Biofuel production, by type, 2015-2021

Source: See endnote 31 for this section.

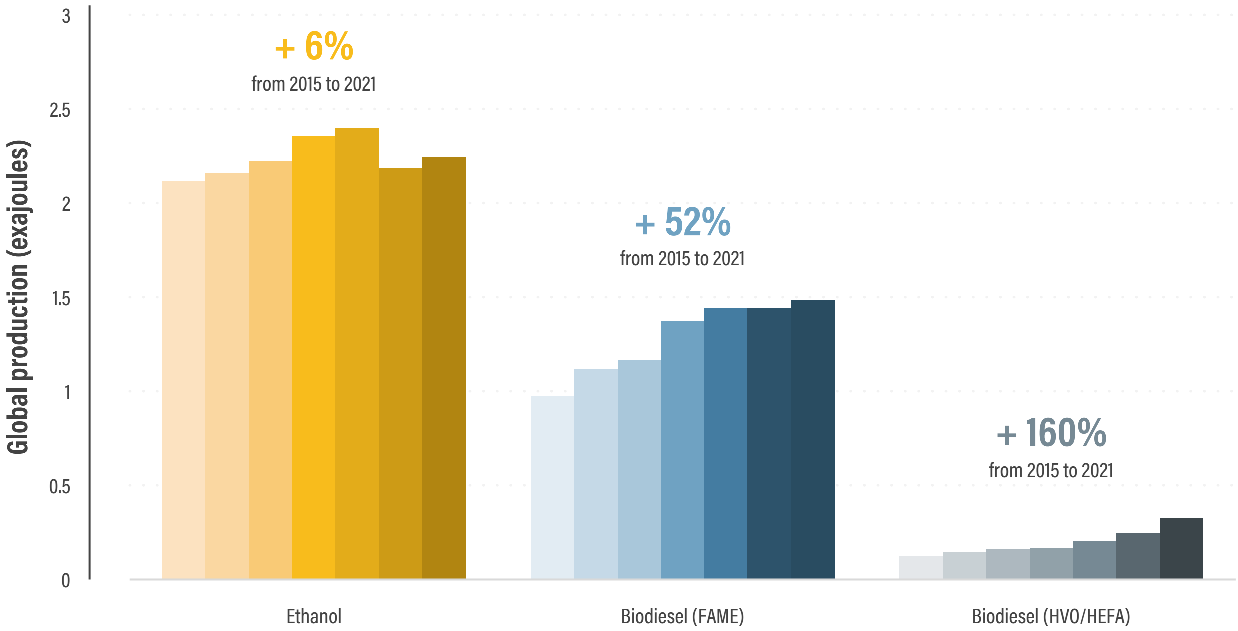
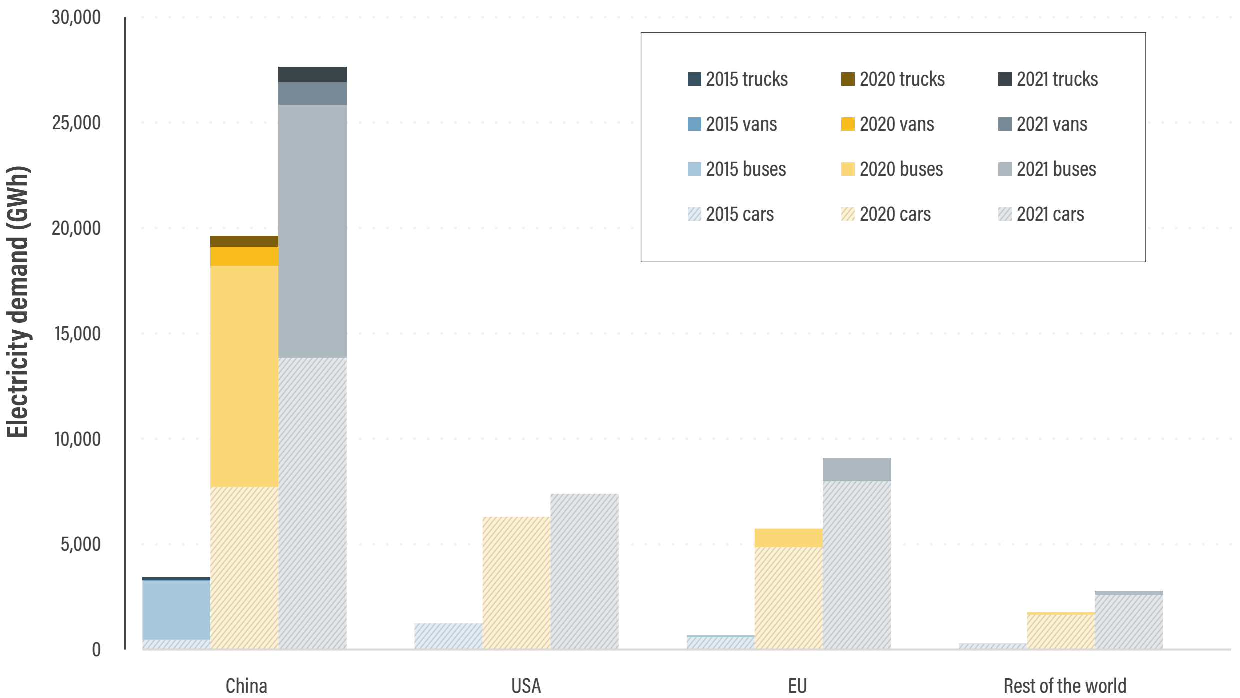


FIGURE 5 Electricity demand from electric vehicles in selected countries/regions, by vehicle type, 2015, 2020 and 2021

Source: See endnote 40 for this section.



of renewables in total global electricity generation was an estimated 28% in 2021, up just 5 percentage points from 2015.[47] However, the share of renewables in global power generation capacity *additions* has increased rapidly since 2010, reaching 83% by 2020.[48] Despite such rapid increases in capacity, the overall growth in electricity demand globally has slowed potential gains in the share of renewables.

More than 450,000 commercial flights used sustainable aviation fuel[i] **(SAF) in 2022, with SAF production increasing 200% compared to 2021.**[49] **However, SAF still accounted for only 0.1% of all consumed aviation fuel as of 2022.**[50] SAF is currently blended with fossil fuel at rates of between 5% and 50%, but the first flight using 100% SAF took off in January 2023, raising hopes of increasing use rates in the future.[51] By the end of 2022, 60 airports, mainly in Europe and the United States, provided continuous supply of SAF blends, up from 46 in 2020, and 30 more airports provided batch deliveries, up from 23 in 2020.[52] (*See Section 3.7 Aviation*.)

i Produced from bioenergy, municipal waste, or synthetically through carbon captured from the air.

Emission trends

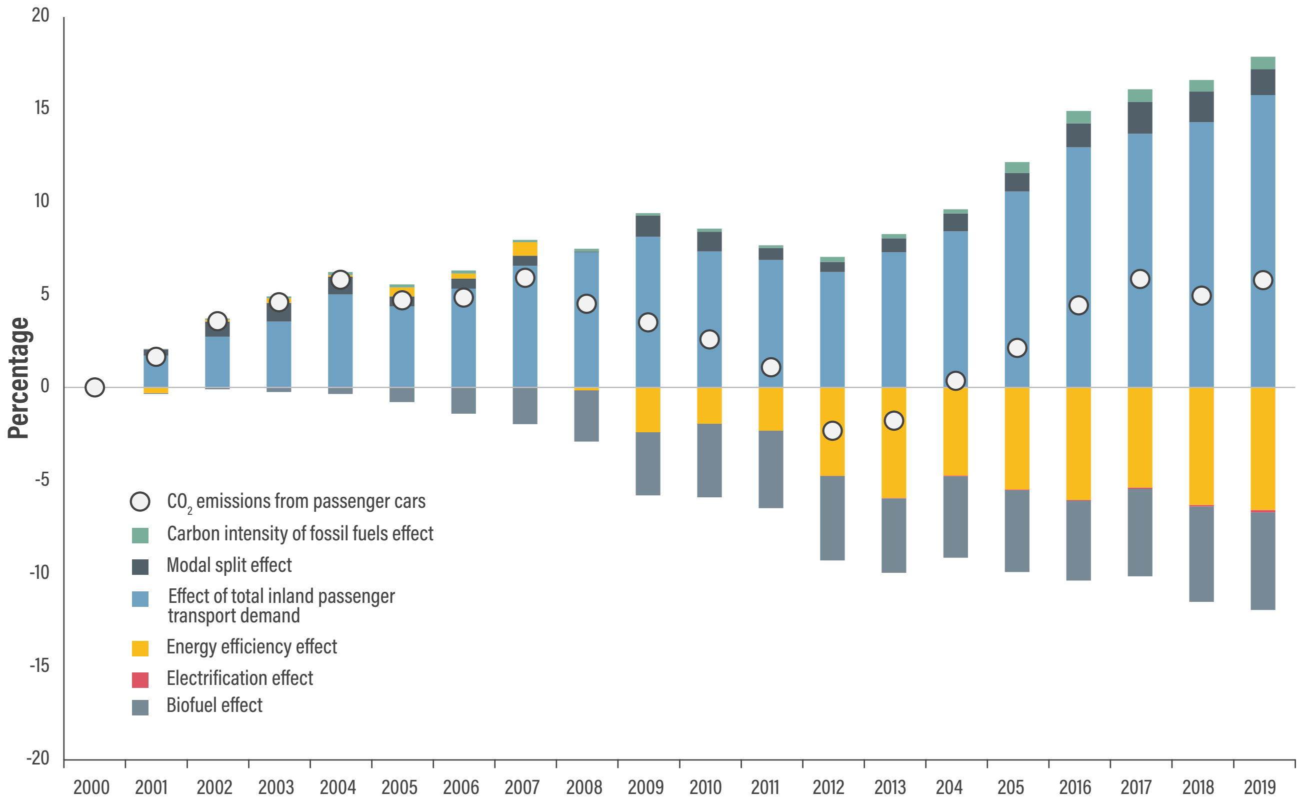
Carbon dioxide (CO_2) emissions from road transport increased steadily between 2000 and 2020 (*see Section 3.6 Road Transport*).[53] Even regions where emission standards were increasingly strict saw growth due to rising transport demand. In the EU, emissions from passenger cars increased 5.8% between 2000 and 2019, despite a 6% decline in energy consumption per passenger-kilometre.[54] The use of biofuels dampened emission increases during this period, as did energy efficiency standards, but electrification did not play a significant role in decarbonising passenger cars in the EU up to 2019 (see Figure 6).[55]

Energy efficiency improvements and the use of renewable energy sources, mostly biofuels, helped reduce emissions from the transport sector. However, these savings continued to be outweighed by rising emissions from the overall growth in transport demand and from the modal shift towards higher-emitting forms of transport, leading to a net increase in emissions from the sector.

The required shift to renewable energy in transport will have negative effects on employment in regions that are highly dependent on fossil fuels. Policies aimed at fostering the decarbonisation of transport will need to ensure an equitable just transition towards more sustainable jobs.[56]

FIGURE 6 Evolution of CO_2 eq emissions from passenger cars in the EU-27, by contributing factor, 2000-2019

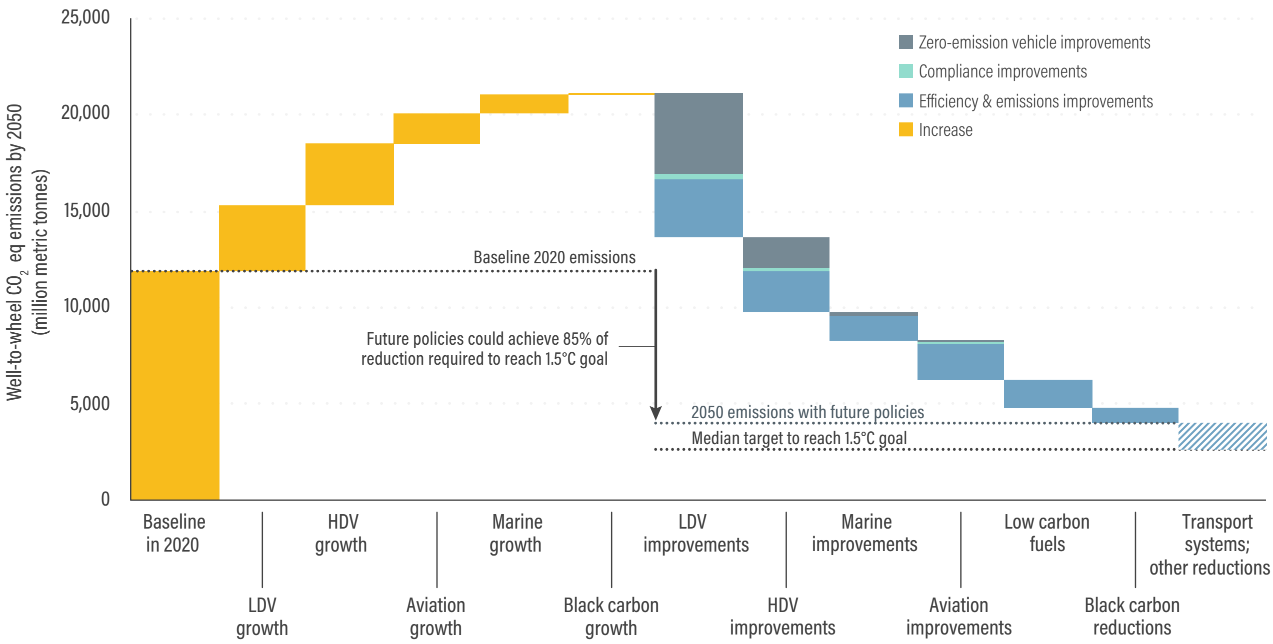
Source: See endnote 56 for this section.



Note: Emission data are measured in CO_2 equivalent emissions and shown as a percentage change compared to the year 2000.

FIGURE 7 Baseline emissions from transport in 2020, and the mitigation potentials from different sectoral activities to 2050

Source: See endnote 62 for this section.



Note: Figure does not show potential reductions from "Avoid" and "Shift" measures.
HDV = heavy-duty vehicle; LDV = light-duty vehicle.

Globally, this shift is expected to result in a net gain in jobs.[57] It is crucial to find tailored solutions that mitigate negative developments and create a more equitable and sustainable system for all stakeholders.[58] According to a 2022 report, the top five countries leading the way on measures to achieve a just transition were Costa Rica, Portugal, Sweden, Argentina, and Spain, while China, Brazil, India, the United States and Europe (as a region) led in renewable energy jobs.[59]

An "ambitious yet feasible" scenario from the International Council on Clean Transportation (ICCT) projects that the energy efficiency of light-duty vehicles will improve 0.75% annually between 2030 and 2050.[60] In the future, zero-emission vehicles are projected to play a major role in emission reductions, especially for road transport. Widespread electrification with renewable sources also offers high potential for emission reductions, and must counteract the expected growth in emissions from rising transport activity and the use of heavier vehicles (see Figure 7).[61]

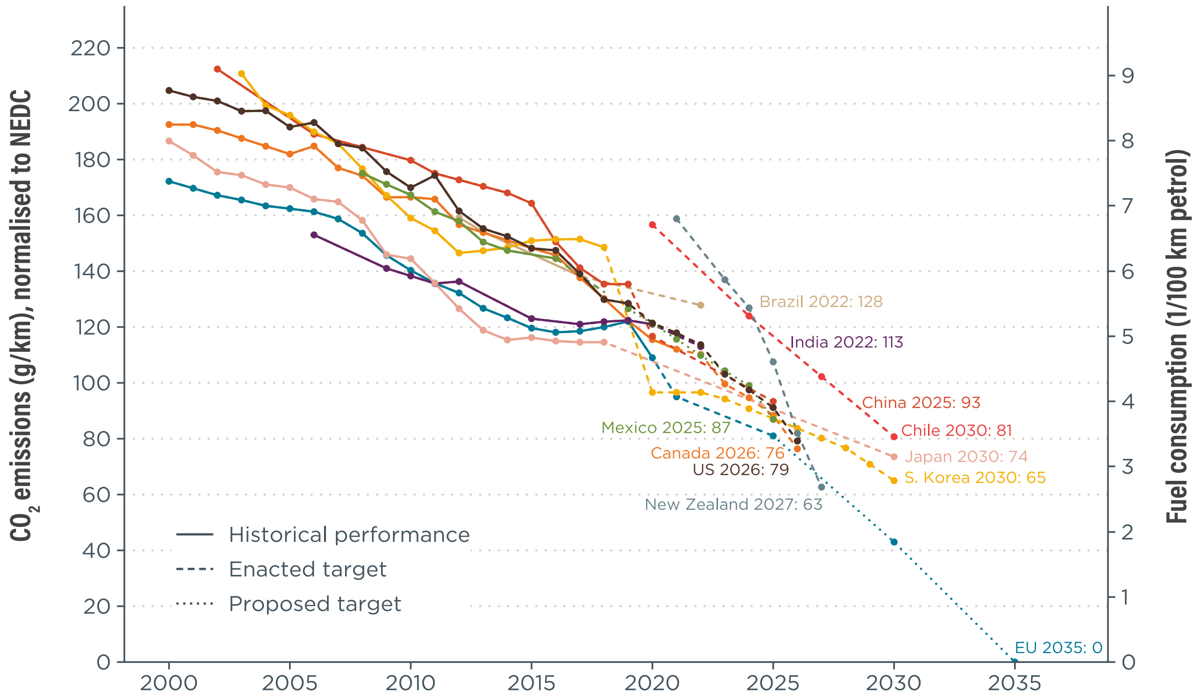
Energy efficiency plays a major role in decarbonising the maritime and aviation sectors under the ICCT's "ambitious yet feasible" scenario. The scenario assumes an improvement in ship efficiency of 70% by 2040, with only 17% of energy demand being met by zero-emission vessels.[62] In aviation, emissions are projected to decrease 40% between 2020 and 2050, with only 10% of liquid fuels being replaced by electrification.[63]

Policy developments

Mandatory standards for energy efficiency and for greenhouse gas emissions have proven to be effective instruments to drive efficiency and the shift to zero-emission vehicles. At least 11 countries plus the EU-27 – covering more than 80% of global passenger car sales – have established or enacted fuel efficiency or greenhouse gas emission standards for passenger cars and light trucks; some countries have proposed strengthening their standards, and at least one new country (Malaysia) has proposed enacting

FIGURE 8 Equivalent passenger car CO_2 emissions and fuel consumption in countries with mandatory vehicle efficiency or emissions standards, 2000-2035

Source: See endnote 66 for this section.



Note: Differences in the test procedures across standards are converted to the New European Driving Cycle (NEDC), a testing method to check fuel economy and emissions. Switzerland and the United Kingdom have adopted EU greenhouse gas emission standards and are included under "EU" in the graph.

mandatory standards.[64] Countries where such standards have been implemented have seen significant reductions in both emissions and fuel consumption (see Figure 8).[65]

- Chile adopted new vehicle efficiency standards under its energy efficiency law, which will come into effect in 2024 for light-duty vehicles and 2026 for medium-duty vehicles, progressing from 18.8 kilometres per litre in 2024 to 28.9 kilometres per litre by 2030 for light-duty vehicles.[66]
- The United States revised its fuel economy standards in 2022, with the new standards aimed at increasing fuel efficiency 8% annually for model years 2024-2025 and 10% annually for model year 2026.[67]
- As part of its Fit for 55 package, the EU adopted higher fleet-wide CO_2 emission reduction targets for new passenger cars and vans, raising reductions to 55% for cars and 50% for vans by 2030, and 100% for both by 2035, effectively banning fossil fuels.[68]
- Malaysia issued a voluntary standard in 2021 for energy-efficient vehicle certificates – including vehicle labelling – and started a public consultation process in 2022 for mandatory greenhouse gas emission standards.[69]

An increasing number of countries – mostly with limited or no domestic vehicle manufacturing – have established vehicle standards or other instruments to enhance the efficiency of imported vehicles. By mid-2020, 67 countries had age restrictions on the import of used vehicles, which influence the fuel efficiency.[70]

- In 2023, New Zealand began operating a Clean Car Standard system that grants importers CO_2 credits for vehicles that have fewer emissions than the individual vehicle target, and imposes charges for vehicles that have higher emissions.[71] The scheme applies to new and used cars and light commercial vehicles; targets are set annually up to 2027, and rates for exceeding the target will increase in 2025.[72]
- In 2020, the 15 member states of the Economic Commission of West African States (ECOWAS) adopted age limits of 5 years for imports of light-duty vehicles and 10 years for heavy-duty

vehicles; members have 10 years to implement the restrictions under the region's new fuel economy roadmap.[73]

- In January 2023, Kenya started enforcing its import bans for motor vehicles older than eight years and for trucks up to 30 tonnes that are older than three years.[74]
- Uganda imposed a ban on the import of motor vehicles older than nine years as of 1 July 2022.[75]
- After the end of Brazil's Invar Auto programme in 2017, which provided tax credits for meeting corporate average vehicle efficiency targets, the country set an efficiency improvement target of 11% over 2017 levels starting in 2022 under its Rota 2030 scheme.[76]

Fuel economy and greenhouse gas emission standards for heavy-duty vehicles are an important instrument to decarbonise the freight sector, particularly given the challenges in finding alternative fuels and propulsion systems for heavy-duty trucks. **In 2022, more than 70% of trucks sold were covered by fuel economy or vehicle efficiency regulations, although only seven countries or regions had such standards** (Canada, China, the EU, India, Japan, the United Kingdom and the United States).[77]

- In 2023, the EU proposed enhanced standards for 2030 that would raise the efficiency improvement target to 45% up from the current 30% and reduce emissions 90% by 2040.[78]
- Chile's Energy Efficiency Law introduces the first standards for medium- and heavy-duty vehicles, which for medium-duty vehicles would be defined in 2024 and take effect in 2026 (and for heavy-duty vehicles in 2026 and 2028, respectively).[79]
- New Zealand adopted a new procurement requirement in 2022 that requires all public transport buses purchased starting in January 2025 to be zero emissions.[80]
- In 2021, 15 countries and regions endorsed the Global Memorandum of Understanding on Zero-Emission Medium and Heavy-Duty Vehicles, committing to 100% zero-emission new truck and bus sales by 2040; as of February 2023, the measure had a total of 27 endorsees including manufacturers, fleet owners, utilities and sub-national entities.[81]
- California (USA) enacted in 2020 the Advanced Clean Trucks regulation, the first regulation worldwide requiring manufacturers to increase the sales share of zero-emission trucks. By 2035, the rule requires a zero-emission share of 40% for tractor trucks (class 7-8), 75% for rigid trucks (class 4-8) and 55% for pick-up trucks and vans (class 2b-3).[82]

Many countries have adopted vehicle labelling schemes to help consumers make informed choices by better understanding the life-cycle costs of vehicles. Several other policies influence the energy efficiency of vehicles, with vehicle taxation often used to steer consumers towards more efficient vehicles.

- In 2022, Viet Nam extended its vehicle labelling scheme to include externally charged hybrid and fully electric vehicles.[83]
- Thailand is adapting its labelling to include watts-per-kilometre for electric vehicles; labelling is particularly relevant in the country because the information is directly linked to vehicle excise tax.[84]
- New Zealand launched an updated vehicle labelling scheme in April 2022 that includes CO_2 emissions and Clean Car Discount eligibility.[85]
- In 2021, Indonesia reformed its vehicle tax structure to include fuel consumption and emission levels.[86]

Biofuel blending mandates remain the most popular measure for increasing renewable energy in transport, with at least 56 countries and the EU having established some form of obligation by the end of 2022.[87] Biofuels policies are driven and restricted by the availability of feedstocks, cost and resulting demand. Countries with abundant feedstocks are more likely to implement blending mandates and generally support biofuel production infrastructure. Requirements regarding the sustainability of biofuels and life-cycle greenhouse gas emissions including land use vary across countries. Several changes to existing mandates emerged in 2021, many in direct response to rising fuel prices:

- Canada replaced its Renewable Fuels Regulations with Clean Fuels Regulations, which take a life-cycle approach and require suppliers to reduce the carbon intensity of diesel and petrol sold in the country, starting in 2023.[88]
- The United Kingdom introduced the mandatory provision of E10 (10% ethanol blend) petrol as the standard in petrol stations, although E5 blends will remain available.[89]
- India released its 2025 ethanol roadmap, which would move up by five years the country's blending mandate for 20% ethanol, to 2025. The roadmap places a renewed focus on food-based feedstocks, despite past challenges in meeting ethanol blend rates, in a departure from the Ethanol Blended Program laid out under the National Policy on Biofuels, which prioritised second-generation feedstocks.[90]
- Argentina lowered its biodiesel blending mandate from 10% to 5% in June 2021 to control rising fuel prices and split its 12% ethanol blending requirement to 6% from sugar cane and 6% from corn.[91] In June 2022, the mandate was raised to 7.5% to increase supply, and in October the government launched a Biofuel Commission, which calls for a 15% ethanol blend mandate and a 1% blend mandate for SAF.[92]
- In 2021, Brazil cut its biodiesel blending mandate from 13% to 10% to counter rising costs; however, government data suggest that blending could return to 15% in March 2023.[93] Still, the country's RenovaBio programme remains the world's largest programme supporting biofuels.[94] In 2023, the

programme updated its mandatory emission reduction targets, while the federal government published guidelines for the implementation of a carbon credit market among biofuels producers and importers.[95]

- Finland temporarily reduced its biofuel blending obligations from 19.5% to 12% for 2022 and from 21% to 13.5% for 2023, in an effort to reduce end-user fuel prices.[96] To compensate for the additional emissions, the government plans to increase its blending obligation for 2030 from 30% to 34%.[97]
- Malaysia pushed the roll-out of its biodiesel blend mandate from 2020 (when it was delayed by the pandemic) to early 2022.[98]

Changes to existing biofuel mandates in 2022 included the following:

- Colombia reduced its ethanol blending mandate from 10% to 6%, while Thailand reduced its biodiesel mandate from 7% to 5%.[99]
- The Czech Republic, Latvia, Peru and Zimbabwe temporarily suspended their biofuel blending mandates.[100] At the sub-national level, New Mexico (USA) also suspended its mandate.[101]
- The Republic of Korea increased its biofuels mandate from 3% to 3.5%, with further increases to occur in 2024 (4%) and 2030 (8%).[102]
- Poland increased its biofuels mandate from 4.95% to 6.2%.[103]

New biofuel policies under development as of 2022 included:

- New Zealand is set to introduce targets to reduce the emission intensity of fuels 2.4% by 2024 (and 9% by 2035) through its Sustainable Biofuels Obligation Bill, which had its first reading in Parliament in November 2022.[104]
- Indonesia was road-testing a 40% biodiesel blend that could lead to a higher ethanol blending mandate by 2025.[105]

As of the end of 2022, at least six countries mentioned biofuel blending in their updated Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement, with policy implementation yet to come.

- Blends mentioned in countries' NDCs include Eswatini (E10 by 2030), Guatemala (B10 by 2032), Lao People's Democratic Republic (10% of transport fuels by 2030), Malawi (E20 by 2040), Mali (5.4% biodiesel and 11% ethanol by 2030) and Vanuatu (B20 by 2030).[106]
- Other countries have set renewable energy targets for the sector in their NDCs, such as Dominica (100% by 2030) and the Republic of North Macedonia (10% by 2030).[107]

In aviation, some countries are considering biofuel blending mandates for sustainable aviation fuels. Additionally, the EU is revising its Emission Trading System (ETS) to apply the polluter pays principle by phasing out free allowances for the aviation sector by 2026.[108] As part of the Fit for 55 package agreed to in December 2022, the EU would include emissions from maritime transport in its ETS starting in 2024, and would create a separate ETS for buildings, road transport and fuels.[109]

- The EU's Fit for 55 package aims to establish an SAF blending mandate starting in 2025, with shares increasing up to 2050.[110]
- In 2022, the United Kingdom confirmed a SAF blending mandate from 2025 requiring at least 10% of jet fuel to be made from sustainable feedstocks by 2030.[111]

MODULE 4 4.2

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Vehicle Technologies

SLOCAT Partnership on Sustainable, Low Carbon Transport

Transport, Climate and Sustainability Global Status Report - 3rd edition

Note: This section is focused on the electrification of transport, covering all transport modes. Major trends for specific modes are captured in other sections, including 3.3 Cycling, 3.5 Intercity Rail Transport, 3.7 National and International Aviation, 3.8 Shipping – Maritime and Inland Waterways, and 4.1 Transport Energy Sources.

Key findings

Demand trends

- Electric four-wheeled vehicles are the fastest growing sector of the clean energy industry. In 2022, global sales of electric cars (including battery electric vehicles and plug-in hybrid electric vehicles) increased 55% – exceeding 10 million units – and nearly every seventh car sold was electric.
- The global electric car fleet increased 154% between 2020 and 2022, maintaining five-year average growth of 53%. The global electric car stock totalled 26 million units in 2022, more than five times the number in 2018. However, electric vehicles still accounted for only around 1% of vehicles globally. In 2022, an estimated 70% of the fleet was battery electric vehicles, and 30% was plug-in hybrids.
- As of 2022, at least 209,000 electric vehicles were deployed in company fleets, around 40,000 more than at the end of 2020.
- Electric two-wheeled vehicles (i.e., electric-assist bikes, mopeds and non-speed-limited motorcycles) dwarf numbers of other electric vehicles, with a total of 275 million units globally in 2022. However, global sales of electric two- and three-wheeled vehicles fell 18% in 2022, from more than 11 million units in 2021 to 9.2 million units. Most sales were in Asia, with China accounting for around 84% of new electric two-wheeled vehicle registrations in 2022.
- The number of electric medium- and heavy-duty trucks increased 19% in 2022 to 322,000 vehicles. Sales of electric trucks increased from 40,000 units in 2021 to around 60,000 units in 2022, although this reflected just 1.2% of total truck sales.
- The global electric van stock grew 45% in 2022, to an estimated 948,000 vehicles, and the electric bus fleet grew 8% to 800,000 vehicles. Electric bus sales represent 4.5% of total new bus sales in 2022.
- Global sales of used electric vehicles have increased, with the European Union (EU), Japan and the Republic of Korea exporting more than 760,000 units between 2017 and 2020.
- Electric vehicle charging infrastructure grew 55% in 2022. An estimated 900,000 new publicly available chargers were installed worldwide during the year, bringing the cumulative total to 2.7 million.
- In 2022 – and for the first time since 2013 – average global prices for electric vehicle batteries rose 7% due to higher material and energy costs during production, a trend that could slow the global uptake of e-mobility solutions.
- Electric vehicle battery swapping systems have continued to grow globally. In 2021, the market was dominated by services catering to passenger electric vehicles, accounting for an estimated 57.5% of the total revenue and led by the increase in electric micro-mobility, such as e-scooters.
- A major driver of future demand for electric vehicles is lower fuel costs, which were at least a third those of diesel and petrol in 2022.

Emission trends

- Global energy consumption for electric mobility increased 22% in 2022, with more than half (59%) of the demand coming from electric cars, followed by electric buses (21%), motorcycles (12%) and trucks (8%). In total, these electric vehicle fleets consumed around 110 terawatt-hours of electricity in 2022.
- Fossil fuel dependency is a major issue in transport and needs to change quickly. Electricity is projected to become the dominant fuel in transport by the early 2040s.
- Aggressive emission reduction pathways aligned with the goal of keeping global warming below 1.5 degrees Celsius (°C) by 2050 feature a significant uptake of electric vehicles, with at least 80% of cars and small commercial vehicles being electric by 2050.
- Although the Russian Federation's invasion of Ukraine led to surging natural gas prices and greater demand for coal, the increased carbon dioxide (CO_2) emissions from coal have been curtailed by the more aggressive deployment of renewable energy technologies (such as solar photovoltaics and wind) and of electric vehicles.
- Overall, battery electric vehicles emit fewer life-cycle greenhouse gas emissions than fossil fuel-powered vehicles, especially when the vehicles are charged using low-carbon electricity.

Policy developments

- Electric vehicles are only one part of the broader transformation needed in transport and mobility systems worldwide to achieve both decarbonisation and sustainability goals, such as access to transport for all, safer roads, cleaner air and livable cities. This transformative change requires an integrated multi-modal, multi-level approach that addresses all aspects of the transport and mobility system.
- Electric vehicle uptake should be framed in a circular economy approach, including the end-of life recycling of batteries as well as the re-use and recovery of other materials (e.g., electronics, metals, minerals).
- More jurisdictions are setting targets for phasing out fossil-fuelled vehicles. As of April 2023, at least 41 countries or sub-national jurisdictions had set phase-out targets for vehicles with internal combustion engines, twice as many as in 2020.
- Many policies related to transport and climate change have highlighted the electrification of buses and/or the procurement of new e-buses, with at least 20 countries announcing such measures during 2020-2022.
- Some governments and other stakeholders have set concrete targets for electric vehicle charging infrastructure.
- Government subsidies for electric vehicles nearly doubled in 2021, approaching USD 30 billion globally. Other economic instruments used to support uptake include tax rebates, feebates and bonus-malus schemes, in which governments incentivise zero- and low-emission vehicles while discouraging high-emission vehicles.
- By the end of 2022, countries' climate strategies were highly favouring electric mobility over other types of actions to mitigate transport emissions.
- In 2021 and 2022, significant global initiatives were focused on the electrification of light-duty as well as medium- to heavy-duty vehicles, covering all major automobile markets and regions.
- Leading automakers are projected to spend an estimated USD 1.2 trillion to 2030 to deliver up to 54 million electric vehicles (and the necessary batteries), accounting for 50% of total vehicle production.
- There is a risk of an electric mobility divide between high-income countries and low- and middle-income countries, in the absence of electrification policies tailored at the economic and regional context.

Overview

Replacing the current fossil-fuelled road transport fleet with low-emission vehicles – powered by electrification, hydrogen, biofuels and e-fuels – is a key strategy towards decarbonisation of transport. Actively supporting the adoption of electric and other low-emission vehicles, along with the necessary enabling infrastructure, is a crucial step towards achieving a sustainable transport system. Managing the overall size and shape of the vehicle fleet goes hand in hand with efforts to manage mobility demand through shifts to sustainable, low carbon transport modes.

Minimising the carbon emissions from vehicle technologies is a key systemic change that is required in the mobility transition. Electric vehicles have zero emissions at the tailpipe and produce far fewer greenhouse gas emissions over their lifetimes than conventional petrol- or diesel-powered vehicles. The carbon footprint of electric vehicles will continue to shrink as they are increasingly powered by renewable electricity sources. In addition to reducing emissions, shifting to low-emission vehicles can improve local air quality, reduce dependence on fossil fuels and lower transport costs. These technologies also hold significant potential for economic development, especially in markets beyond traditional auto manufacturing countries.

However, the overall contribution of low-emission vehicles to climate change mitigation and sustainable development depends critically on their integration with other pillars of the system. Low-emission vehicles need to be fit-for-purpose, meaning that they must be both resource- and energy-efficient. This strengthens the case for electric micro-mobility (two- and three-wheelers and a more diverse set of four-wheelers, including two-seaters, small vans and trucks, and light electric freight vehicles) and points to the cost-effectiveness of more systemic approaches to transforming transport.[1] In recent years, many countries have shifted their approach from encouraging the uptake of electric vehicles towards setting phase-out targets for conventionally fuelled vehicles.

Vehicle electrification strategies should be seen in light of other options for reducing emissions from transport, such as “avoid, shift and improve” strategies. For passenger transport, a high-shift scenario to either electric vehicles or public transport alone would be insufficient to reduce emissions to levels required to avoid climate change.[2] Achieving a net zero emission pathway requires considering all available options to provide access to sustainable mobility for all, including vehicle technologies, modal choice and compact urban design. It is critical to adopt an integrated, multi-modal approach that addresses all aspects of the mobility system, that aligns with national and local policies, and that involves both public and private sector action.

Although low-emission vehicles are a crucial aspect of decarbonising the land transport sector, they are not a sufficient solution. A world with 2 billion low-emission cars would still be unsustainable due to increased traffic congestion, displacement of land for highways and parking, and destruction of ecosystems for mineral extraction.

As an energy end-use sector, transport is directly linked to Sustainable Development Goal (SDG) 7 (affordable and clean energy). Stakeholders can contribute to SDG 7 by increasing the share of renewables in the energy mix and by implementing measures to improve passenger/freight output per unit of energy input. Transport systems also impact SDG 9 (industry, innovation and infrastructure) and SDG 12 (responsible consumption and production), and they are impacted in part by measures taken by governments and industry to achieve these goals.[3]

Demand trends

Electric four-wheeled vehicles are the fastest growing sector of the clean energy industry.[4] In 2022, global sales of electric cars (including battery electric vehicles and plug-in hybrid electric vehicles) increased 55% – exceeding 10 million units – and nearly every seventh car sold was electric.[5] The share of electric cars in all car sales globally increased from 9% in 2021 to 14% in 2022.[6] Around 60% (6.2 million) of the electric cars sold in 2022 were in Asia, followed by 26% in Europe and 11% in North America (see Figure 1).[7]

- China accounted for 60% of the growth in electric car sales in 2021 and 2022, with the number of electric cars sold in the country in 2021 (3.2 million) exceeding the total number sold worldwide in 2020.[8]
- Electric vehicle sales in Europe grew more than 15% in 2022 (total sales of 2.3 million), while North America sold an additional 300,000 electric vehicles that year (total sales of 726,000).[9]
- Low-emission vehicle trends in other regions can be found in the respective regional overviews (*see Section 2.1 Africa, Section 2.4 Latin America and Caribbean*, and *Section 2.6 Oceania*).
- Overall, vehicle sales (of all types) slowed between 2020 and 2022, due in part to disruptions caused by the pandemic and by the Russian Federation's invasion of Ukraine.[10] The pandemic led to the disruption of supply chains, affecting the production and distribution of vehicles.[11] At the same time, visible improvements in urban air quality early in the pandemic paralleled greater demand for cleaner electric mobility.[12]

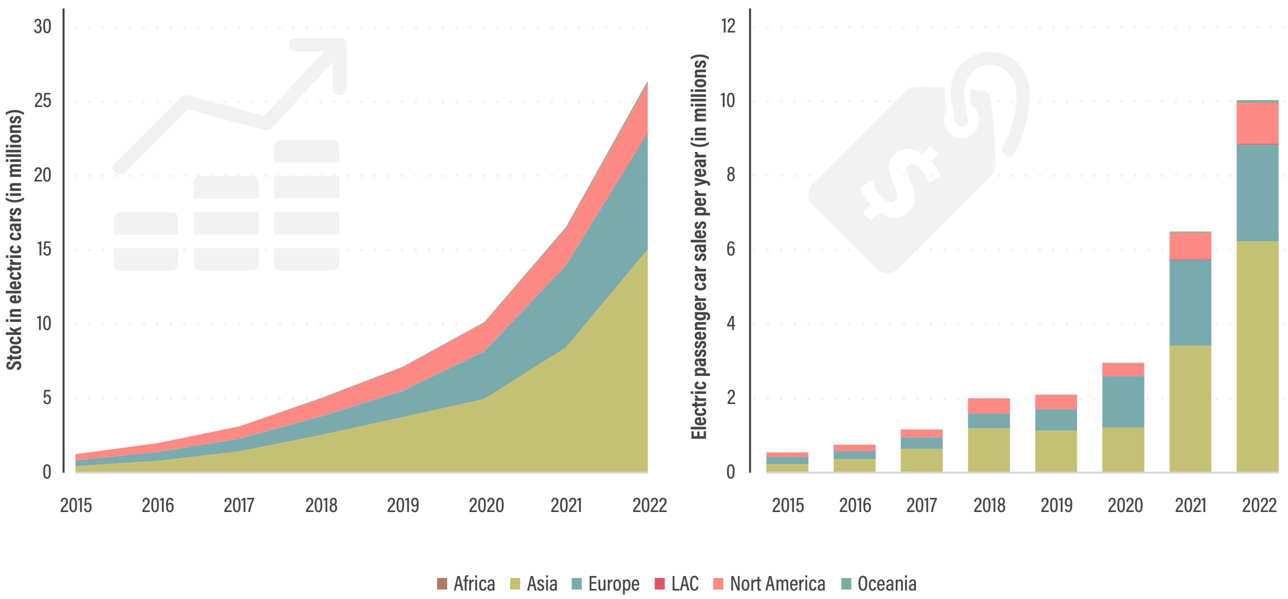
The global electric car fleet increased 154% between 2020 and 2022, maintaining five-year average growth of 53%.[13] The global electric car stock totalled 26 million units in 2022, more than five times the number in 2018 (see Figure 1).[14] **However, electric vehicles still accounted for only around 1% of vehicles globally.[15] In 2022, an estimated 70% of the fleet was battery electric vehicles, and 30% was plug-in hybrids.[16]**

As of 2022, at least 209,000 electric cars were deployed in company fleets, around 40,000 more than at the end of 2020.[17] The company EV fleet is supported by nearly 21,000 charging units installed in more than 3,000 locations worldwide.[18] In Europe, six out of ten cars sold in 2020 were company vehicles, but 87% of them were fossil fuel-powered vehicles, pointing to the need to prioritize electrification of company fleets.[19]

Electric two-wheeled vehicles (i.e., electric-assist bikes, mopeds and non-speed-limited motorcycles) dwarf numbers of other electric vehicles, with a total of 275 million units globally in 2022.[20] However, global sales of electric two- and three-wheeled vehicles fell 18% in 2022, from more than 11 million units in 2021 to 9.2 million units.[21] The main reason for the drop was supply chain challenges in China related to the COVID-19 pandemic, which led to lower sales in the country's domestic market.[22]

FIGURE 1. Electric passenger car stock (left) and sales (right), 2015-2022

Source: See endnote 7 for this section.



- **Most sales were in Asia, with China accounting for around 84% of new electric two-wheeled vehicle registrations in 2022.**[23] Almost every second electric vehicle sold in China was an electric two-wheeler in 2022.[24]
- India added 300,000 electric two- and three-wheelers in 2021, Viet Nam added 230,000 units, and Europe added 87,000 units.[25] (*For more on electric-assist bikes, see Section 3.3 Cycling.)*

The number of electric medium- and heavy-duty trucks increased 19% in 2022 to 322,000 vehicles.[26] **Sales of electric trucks increased from 40,000 units in 2021 to around 60,000 units in 2022, although this reflected just 1.2% of total truck sales.**[27]

- In 2022, 95% of electric truck sales were in China, with most of the electric trucks having a gross vehicle weight of under 4.5 tonnes.[28]
- The number of electric truck models increased significantly as 220 new models were released in 2022, showing that truck electrification has become increasingly popular among vehicle manufacturers.[29]

The global electric van stock grew 45% in 2022, to an estimated 948,000 vehicles, and the electric bus fleet grew 8% to 800,000 vehicles.[30] **Electric bus sales represent 4.5% of total new bus sales in 2022.**[31]

- In 2021, the strongest growth in electric vans and light commercial vehicles was in the Republic of Korea, representing 12% of all van sales and increasing from 1,500 vehicles in 2019 to 28,000 vehicles in 2021.[32] China was home to 60% of the global van fleet in 2022.[33]
- China continues to dominate the electric bus and truck market, accounting for about 96% of the estimated global electric bus as well as the electric truck stock in 2022.[34]
- Battery-electric buses became the dominant type of bus sales in the EU in 2019. In Europe, more than 3,400 e-buses were delivered in 2022 – bringing the total operational stock to more than 11,600.[35] As of 2022, more than two thirds of new bus registrations in the EU were electric and a third of the total bus stock was electric.[36]
- In 2021, for the first time, at least three countries in Europe (France, Germany and the United Kingdom) registered more than 500 e-buses each.[37] The European Automobile Manufacturers' Association estimated that e-buses account for more than 6% of bus registrations in the EU as of 2021.[38]

Global sales of used electric vehicles have increased, with the European Union (EU), Japan and the Republic of Korea exporting more than 760,000 units between 2017 and 2020.[39] Although uptake of electric vehicles in many low- and middle-income countries has lagged, opportunities to transfer cleaner vehicle technologies have arisen through used vehicle markets.[40]

Electric vehicle charging infrastructure grew 55% in 2022.[41] **An estimated 900,000 new publicly available chargers were installed worldwide during the year, bringing the cumulative total to 2.7 million.**[42] Annual growth in charging infrastructure in 2022 exceeded pre-COVID-19 levels for 2015-2019, which were around 50%.[43] Most public chargers – just over two-thirds (67%) – were slow chargers in 2022.[44]

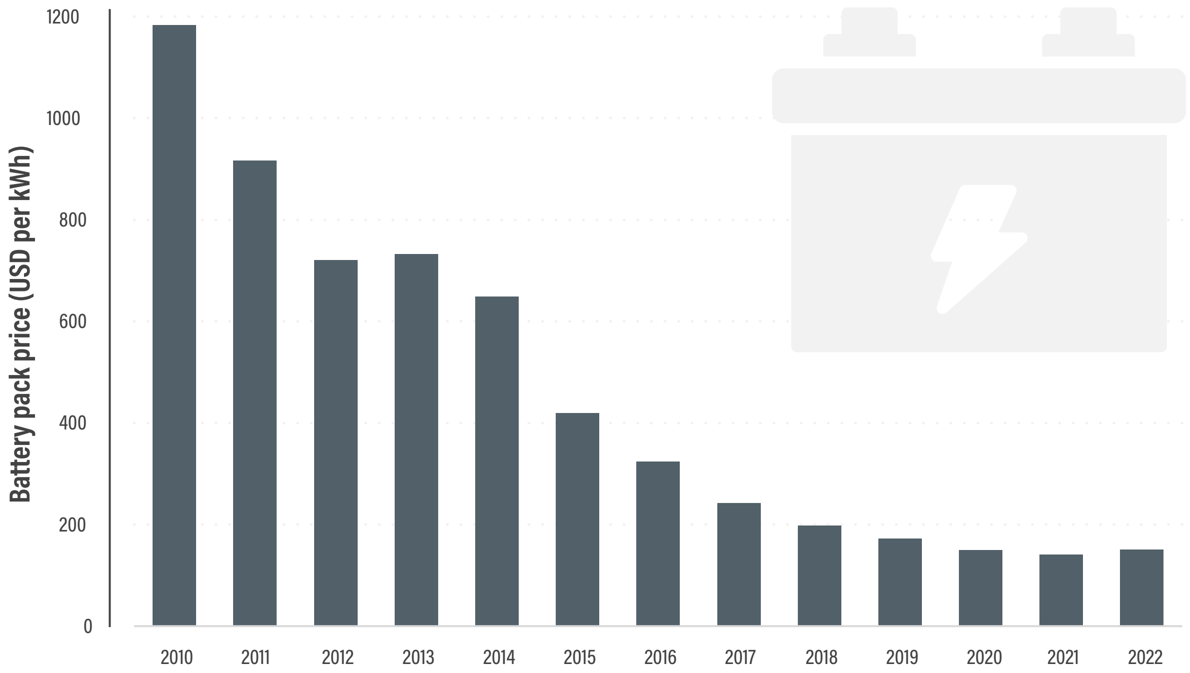
- China was home to roughly two-thirds (62%) of the world's public chargers in 2022, or more than 1.7 million.[45] The Republic of Korea – with 201,000 public chargers, or 7% of the global total – overtook the United States (with 130,000, or 5%) during the year.[46]
- By the end of 2022, Europe had 430,000 electric vehicle chargers, of which 73% were medium-speed alternating current chargers.[47]
- The Republic of Korea boasts the highest density of charging locations, with 75 locations per 100 kilometres of roadway in 2022, followed by the Netherlands with 22 locations and Norway with 13.[48]
- Fast-charger installations in China grew more than 61% in 2022 – reaching a total of 760,000 – driven by government subsidies and by rapid deployment by public utilities.[49]
- The ratio of electric vehicles to charging points remained relatively constant between 2015 and 2022, at fewer than 10 vehicles per charging point in China, the Republic of Korea and the Netherlands.[50]
- In the United States, where growth in the electric vehicle fleet has outpaced the installation of public charging stations, the ratio of electric vehicles to charge points was 24 to 1 in 2022.[51] In Europe, the ratio was around 12 to 1 by year's end.[52]

In 2022 – and for the first time since 2013 – average global prices for electric vehicle batteries rose 7% due to higher material and energy costs during production (see Figure 2)**, a trend that could slow the global uptake of e-mobility solutions.**[53] Battery price increases are expected to translate to overall increases in the price of electric vehicles, a deviation from the trajectory outlined in the previous edition of this report.

- The Russian Federation's invasion of Ukraine impacted the production and price of electric vehicles, particularly in Europe.[54] Both countries are primary sources of elements needed in electric vehicle production, such as high-grade nickel, palladium and neon.[55] The effects of the war – including economic sanctions, damage to infrastructure and displacement of workers in Ukraine's electric vehicle industry – have all impacted the industry.[56]
- Prices of lithium-ion battery packs increased 7% in 2022, due mainly to the rising costs for input metals such as lithium, nickel, cobalt and manganese.[57] This was a reversal of the

FIGURE 2. Battery price development, 2010-2022

Source: See endnote 53 for this section.



long-term trend from 2010 to 2021, when battery prices fell 88% as the industry adopted lower-cost chemistries such as lithium iron phosphate (LFP), which were 30% cheaper than nickel manganese cobalt (NMC) cells.[58]

- Some predict that battery pack prices will continue to rise until 2026, while others suggest a sustained price of around USD 151 per kilowatt-hour (kWh) to 2024, when more lithium production is expected to come online.[59] However, a meta-analysis predicts a decrease to USD 132 per kWh by 2030 and USD 71 per kWh by 2050.[60]
- For the electric vehicles sold in 2018, the estimated material demand was 11 kilotonnes of lithium, 11 kilotonnes of manganese, 15 kilotonnes of cobalt and 34 kilotonnes of nickel.[61] The demand for these materials could increase 25- to 30-fold until 2030.[62]

Electric vehicle battery swapping systems have continued to grow globally. In 2021, the market was dominated by services catering to passenger electric vehicles, accounting for an estimated 57.5% of the total revenue and led by the increase in electric micro-mobility, such as e-scooters.[63]

- As of 2023, the Chinese manufacturer Nio had installed 10 battery swapping stations across Europe, and it aims to have 120 stations in the region by the end of 2023.[64]
- Gogoro, which introduced a Smartscooter that integrates battery swapping systems, reported more than 450,000 users across some 2,200 swapping stations; in Chinese Taipei, the stations are estimated to be available every 500 metres.[65]
- In 2022, North America accounted for a quarter of the total revenue from the electric vehicle battery swapping market.[66]

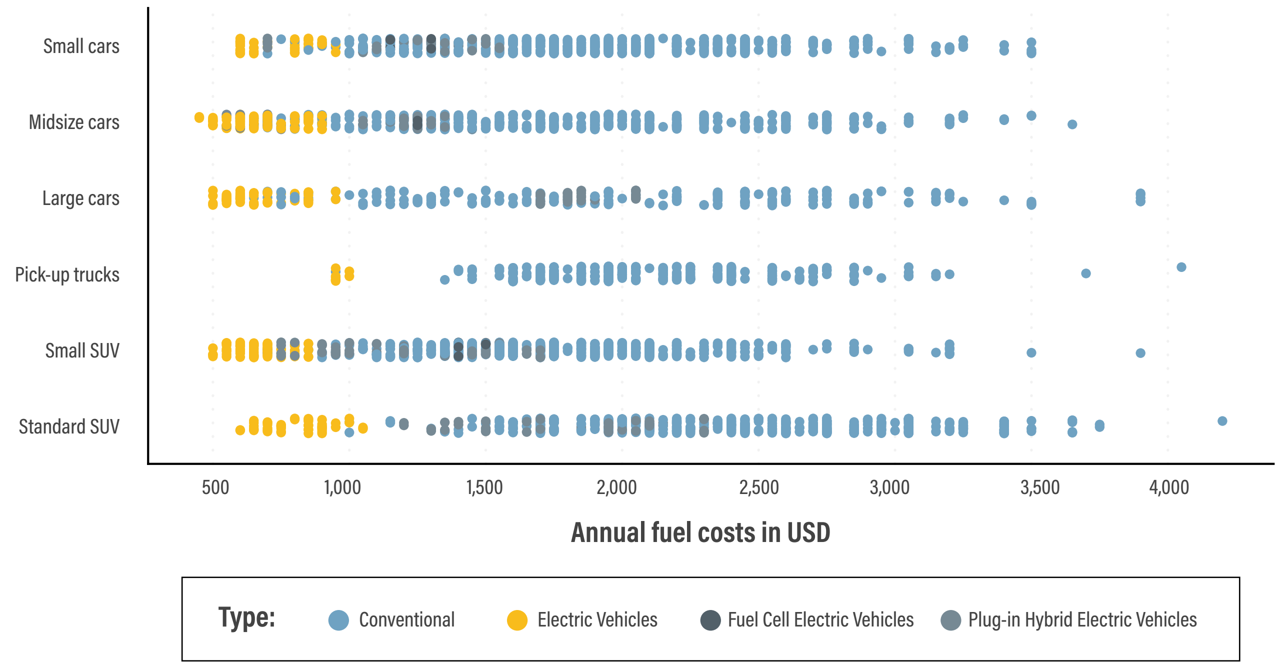
A major driver of future demand for electric vehicles is lower fuel costs, which were at least a third those of diesel and petrol in 2022.[67] Electric passenger cars released between 2021 to 2023 in the United States showed the lowest annual fuel costs per household among all fuel types (see Figure 3).[68] The average annual expenses for a conventional mid-size car were three times higher than for an electric car of the same size.[69]

Emission trends

Global energy consumption for electric mobility increased 22% in 2022, with more than half (59%) of the demand coming from electric cars, followed by electric buses (21%), motorcycles (12%) and trucks (8%).[70] **In total, these electric vehicle fleets consumed around 110 terawatt-hours of electricity in 2022.**[71] The emission benefits of electric vehicles can be maximised by charging the vehicles using renewable-

FIGURE 3. Annual fuel cost for vehicle types in the United States, based on 2021-2023 models

Source: See endnote 68 for this section.



based electricity.[72] This highlights the urgent need to integrate higher shares of renewable energy in the overall electricity mix.[73]

Fossil fuel dependency is a major issue in transport and needs to change quickly. Electricity is projected to become the dominant fuel in transport by the early 2040s.[74] Compared to other strategies to decarbonise transport, electrification of passenger vehicles (two- and four-wheelers) is "well underway" and is expected to advance exponentially.[75]

- In 2021, emissions from oil remained below pre-pandemic levels because global transport activity was limited.[76] As COVID-19 travel restrictions eased substantially in 2022, oil-related CO_2 emissions rose an estimated 180 million tonnes.[77]
- Among 13 transport targets – such as the development of public transport, cycling infrastructure, sustainable aviation fuels, etc. – only the two electrification targets (for electric light-duty vehicle sales and electric bus sales) are going in a promising direction, while all others are well off track.[78]

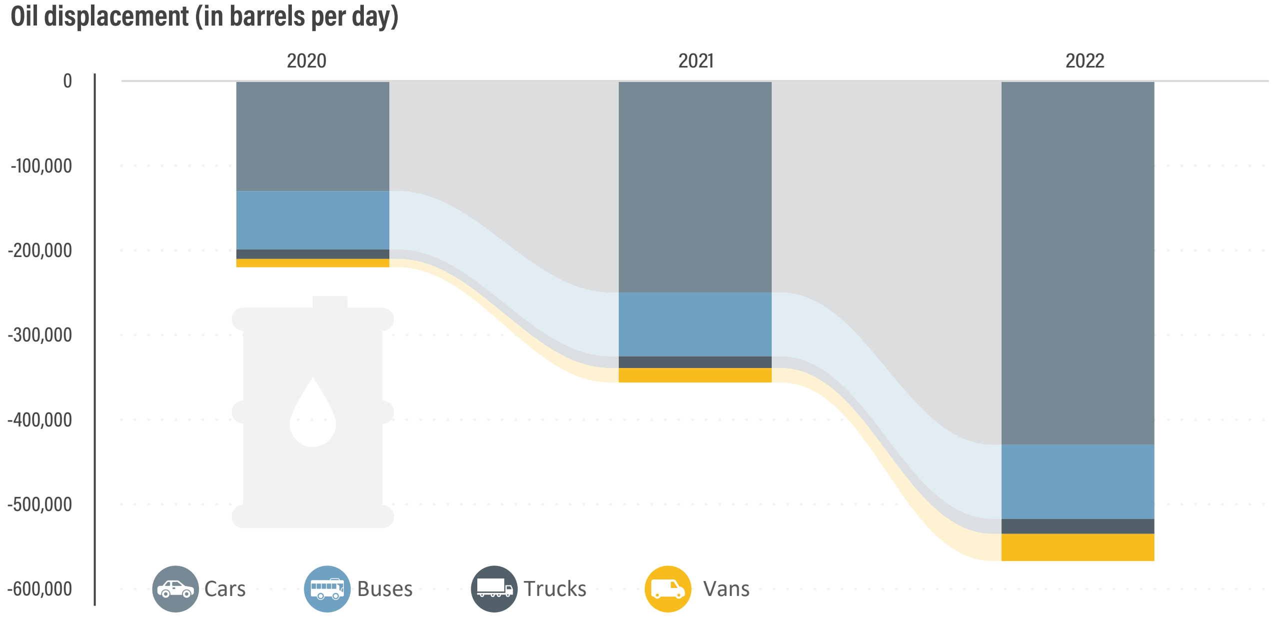
Aggressive emission reduction pathways aligned with the goal of keeping global warming below 1.5°C by 2050 feature a significant uptake of electric vehicles, with at least 80% of cars and small commercial vehicles being electric by 2050.[79]

- Under current policies, electric vehicles will avoid 700 million tonnes of greenhouse gas emissions annually by 2030.[80] However, to reach net zero emissions by 2050, the emission savings need to surpass 1,100 million tonnes annually by 2030, with electric heavy-duty vehicles (buses and trucks) contributing 25% of the avoided emissions.[81]
- A 2022 study shows that to keep global warming below 1.5°C, automobile manufacturers have to halve their future sales of internal combustion engine vehicles (from a range of 546 to 778 million vehicles between 2020 and 2050, to 330 to 463 million).[82]
- The previous edition of this report suggested that envisioned electric vehicle production levels would not supply enough vehicles to meet government-set targets.[83] Although auto manufacturers have since increased their electric vehicle ambitions, the current estimate is that electric vehicles need to represent 52% of total vehicle production by 2029 to support the 1.5°C target (*see Section 1.3.3 The Role of Business in Decarbonising Transport*).[84]

Although the Russian Federation's invasion of Ukraine led to surging natural gas prices and greater demand for coal, the increased CO_2 emissions from coal have been curtailed by the more aggressive deployment of renewable energy technologies (such as solar photovoltaics and wind) and of electric vehicles.[85] Electric vehicles were also able to displace 567,000 barrels oil per day in 2022, a 59% increase compared to 2021 (see Figure 4).[86]

FIGURE 4. Oil displacement through electric vehicles, 2020-2022

Source: See endnote 86 for this section.



- Electric vehicles alone enabled a net reduction of an estimated 80 million tonnes of greenhouse gas emissions (well-to-wheel emissions) in 2022, double the amount reduced in 2021.[87] Electric vehicles in China provided the biggest emission savings (30% of the total savings) in 2022.[88]
- A 2022 study found that in Germany, light-electric vehicles (such as scooters, e-bikes, motorcycles and small cars) could replace half of all kilometres driven by medium-sized fossil fuel cars, avoiding a total of 57 million tonnes of greenhouse gas emissions annually by 2030.[89]
- The electric bus fleet in Latin America saved 129,070 tonnes of CO_2 annually in 2021.[90] Two years later, in 2023, the savings had more than tripled, to 404,190 tonnes of CO_2 annually.[91]

Overall, battery electric vehicles emit fewer life-cycle greenhouse gas emissions than fossil fuel-powered vehicles, especially when the vehicles are charged with low-carbon electricity.[92] However, critics have raised concerns about emissions released during the production and recycling of electric vehicles and their components, notably the batteries.[93]

- A 2020 study found that, on average, even very inefficient electric vehicles release fewer life-cycle emissions than very efficient new petrol vehicles, if the average emission intensity of electricity is below 700 grams of CO_2 equivalent per kilowatt-hour.[94] A passenger electric vehicles would result in a 29% reduction in greenhouse gas emissions on average (up to 1.5 gigatonnes of CO_2 annually).[95]
- These findings are consistent with a 2019 study showing that electric vehicles are poised to result in significant emission savings – even if these vehicles are assumed to have lower lifespans, which in turn reduces the operational emission savings (which in themselves are much lower than for fossil-based vehicles).[96]
- Electric vehicles, in combination with low-emission electricity, offer the largest potential for decarbonising land transport on a life-cycle basis, according to the Intergovernmental Panel on Climate Change.[97] To address growing concerns about the impacts of batteries and the critical minerals needed to produce them, manufacturers can seek to diversify materials and supply, improve energy and material efficiency, and support greater circularity.[98]
- Researchers found that putting a price on indirect emissions (i.e., from electricity grids) can lead to an increase, rather than a decrease, in electric vehicle sales, which would bring additional opportunities to reduce both cumulative tailpipe and indirect emissions.[99]
- A 2022 study found that circular strategies could cut the emissions from materials used in vehicles (of all types) as much as 60% by 2040; currently, 78% of a vehicle is recyclable, but this share could be increased to 97% by 2040.[100]

Policy developments

Electric vehicles are only one part of the broader transformation needed in transport and mobility systems worldwide to achieve both decarbonisation and sustainability goals, such as access to transport for all, safer roads, cleaner air and livable cities. This transformative change requires an integrated multi-modal, multi-level approach that addresses all aspects of the transport and mobility system.

- Providing high-quality public transport services and walking and cycling infrastructure is a core part of achieving access to transport for all. To enable this, densification characterised by compact city development can help with mixed-use, poly-centric structures, and short travel distances.
- Sharing should include pooling and public transport feeder systems as well as access to shared cars and ride-hailing services. Pricing systems should be harmonised across these services and encourage the use of the most efficient options.
- For greater efficiency, drastically downsizing both the size and power of vehicles is vital – making electrification of the entire vehicle fleet both cost-effective and feasible. This is counter to the ongoing trend towards bigger, faster and more powerful cars, which has eradicated almost all efficiency gains in powertrain technologies. Electric vehicle concepts should focus on the most viable and resource-efficient solutions.

Electric vehicle uptake should be framed in a circular economy approach, including the end-of life recycling of batteries as well as the re-use and recovery of other materials (e.g., electronics, metals, minerals).[101] However, there are very few efforts in this direction.

In 2023, the EU approved new rules ensuring that the increased demand for electric vehicle batteries will be met by more environmentally sustainable batteries, with lower emissions and sourced from recycled materials.[102]

More jurisdictions are setting targets for phasing out fossil-fuelled vehicles. As of April 2023, at least 41 countries or sub-national jurisdictions had set phase-out targets for vehicles with internal combustion engines, twice as many as in 2020.[103] As of 2020, only 19 countries or sub-national jurisdictions had set targets to phase out diesel and petrol passenger vehicles.[104]

- Previously, many individual EU member countries (Austria, Denmark, France, Ireland, Italy, the Netherlands, Portugal, Slovenia, Spain, Sweden) had set targets for phasing out internal combustion engine vehicles. In early 2023, the EU passed regionwide legislation to ban sales of new fossil fuel-powered cars and vans by 2035; Germany opposed the ban until the legislation allowed for the continued sale of combustion-engine cars running on synthetic e-fuels, which might still produce CO_2 emissions.[105]
- In 2023, the EU proposed that only zero-emission buses could be sold in the region starting in 2030, and that by 2040 new trucks would need to produce at least 90% fewer CO_2 emissions compared to 2019 levels.[106]
- Chile in 2021 announced a target for 100% sales of zero-emission light-duty vehicles by 2035.[107]
- In 2023, the US Environmental Protection Agency proposed strengthening fuel economy standards 2% per year for passenger cars and 4% per year for light trucks from 2027 to 2032, in order to reduce CO_2 emissions 56% below 2026 levels by 2032.[108]
- In 2022, Canada moved its target for banning internal combustion engine cars forward by five years, from 2040 to 2035, including a medium-term zero-emission sales target of 20% by 2026; in addition, medium- and heavy-duty vehicles should be 35% electric by 2030 and 100% electric for certain categories by 2040.[109]
- California (USA) is one of the world's largest economies with a phase-out policy, targeting a phase-out of internal combustion engine passenger cars by 2035.[110] In 2023, California also set a target for half of all heavy-duty trucks sold in the state to be electric by 2035.[111]

Many policies related to transport and climate change have highlighted the electrification of buses and/or the procurement of new e-buses, with at least 20 countries announcing such measures during 2020-2022.[112]

- Most e-bus schemes target general public transport uses, as in Bogotá (Colombia), Hamburg (Germany) and Nepal; however, Canada and the United States have also targeted the electrification of school buses.[113]
- Several cities, such as Bogotá (Colombia) and São Paulo (Brazil) have banned the purchase of new diesel buses.[114]
- Berlin (Germany) and Santiago (Chile) are among the cities targeting 100% zero-emission bus fleets within the coming decades.[115] Other municipal targets for zero-emission bus fleets range from 20% to 80%.[116]
- India's FAME-II scheme aggregates demand for e-buses.[117] It enabled one of the largest tenders for electric buses in the world with 5,450 electric buses for five cities in 2022.[118] The Indian state of Tamil Nadu is targeting a 30% electric bus fleet by 2030.[119] In 2023, India launched the National Electric Bus Programme aiming to deploy 50,000 electric buses by 2027.[120]
- As of 2022, 37 cities had signed the C40 Green and Healthy Streets Declaration, pledging to only procure zero-emission buses starting in 2025.[121]
- Cambodia reduced its import duties on electric vehicles in 2021 and aims to electrify 40% of its urban buses by 2050.[122]

- Kenya is partnering with the EU to develop a network of five electric bus rapid transit lines – the first in East Africa – which are expected to enter service in 2030.[123]
- Viet Nam's transport sector action plan mentions that all new buses procured from 2025 will be zero-emission.[124]

Policies related to the electrification of two- and three-wheelers are also increasing in all major regions.

- Various cities, including Mumbai (India) and Stockholm (Sweden), support the procurement of e-bikes for bike sharing purposes.[125]
- France offers incentives of up to EUR 4,000 (USD 4,310) to swap out an old polluting car with an e-bike.[126]
- Various countries, such as Guatemala, India, and Sudan, have enacted measures to convert diesel and petrol-powered three-wheelers to electric.[127]
- To alleviate air pollution, Delhi (India) banned new registrations of diesel auto-rickshaws starting in 2023, and it plans to only allow natural gas-powered or electric rickshaws starting in 2027.[128]
- Uganda is partnering with SPIRO, a vehicle and battery design company, to roll out 140,000 electric motorbikes and up to 3,000 battery charging and swapping stations across the country.[129]

Some governments and other stakeholders have set concrete targets for electric vehicle charging infrastructure. In addition to expanding and funding national charging networks, several countries have encouraged charging infrastructure in homes and on other private property.

- England is reportedly incorporating mandatory electric vehicle charger requirements for new homes and buildings in its new building codes by 2023.[130] The United Kingdom aims to have 300,000 charging stations by 2030.[131]
- In October 2022, the European Parliament adopted minimum requirements for charging infrastructure as part of the Alternative Fuels Infrastructure Regulation; EU Member States are now required to build charging points along at least every 60 kilometres of motorways by 2026.[132]

Government subsidies for electric vehicles nearly doubled in 2021, approaching USD 30 billion globally.[133] Other economic instruments used to support uptake include tax rebates, feebates and bonus-malus schemes, in which governments incentivise zero- and low-emission vehicles while discouraging high-emission vehicles.[134]

- China extended its subsidy scheme for new energy vehicles, including electric vehicles, through 2022.[135] However, it reportedly cut these subsidies 30% that year.[136]
- The Republic of Korea introduced a subsidy scheme that applied to low-emission cars priced under KRW 90 million (USD 78,671) in 2021, and KRW 55 million (USD 48,077) in 2022.[137]
- In 2022, New Zealand started a feebate programme for battery electric vehicles and plug-in hybrid electric vehicles, which contributed to a large increase in electric vehicle sales following implementation.[138]

By the end of 2022, countries' climate strategies were highly favouring electric mobility over other types of actions to mitigate transport emissions.

- An estimated 55% of the second-generation Nationally Determined Contributions (NDCs) (79 NDCs) submitted by countries under the Paris Agreement feature e-mobility-related transport mitigation actions.[139]
- In the second-generation NDCs, the attention moved away from public transport actions and towards e-mobility actions, such that for every public transport action there are now two electric mobility actions mentioned.[140]
- The e-mobility actions feature a diversity of road transport modes, with buses and cars each representing 20% of all e-mobility actions mentioned (*see Section 1.3.1 National Climate and Sustainability Strategies to Achieve the Targets of the Paris Agreement and the SDGs on Transport*).[141]

In 2021 and 2022, significant global initiatives were focused on the electrification of light-duty as well as medium- to heavy-duty vehicles, covering all major automobile markets and regions.

- At the 2021 United Nations (UN) Climate Change Conference in Glasgow, United Kingdom (COP 26), a declaration emerged on accelerating the transition to 100% zero-emission cars and vans; this action was later renamed the Accelerating to Zero Coalition at the 2022 UN Climate Change Conference in Sharm-el Sheikh, Egypt (COP 27).[142] The declaration, which had received well over 200 signatories by 2023, aims for all sales of new cars and vans to be zero emission by 2040.[143]
- Also at COP 26, a Memorandum of Understanding on Zero Emissions Medium- and Heavy-Duty Vehicles was launched, with the goal of achieving 100% zero-emission new truck and bus sales by 2040.[144]

Leading automakers are projected to spend an estimated USD 1.2 trillion to 2030 to deliver up to 54 million electric vehicles (and the necessary batteries), accounting for 50% of total vehicle production.[145] As of 2023, however, only two auto manufacturers (Tesla and BYD) were seen as leaders in the zero-emission vehicle transition.[146] In addition, virtual power grids, which allow for aggregation of decentralised energy sources such as electric vehicles, are gaining traction.

- Volkswagen has announced that it will produce only electric vehicles in Europe as of 2033, and Mitsubishi aims to only sell electric vehicles by 2035; new vehicles manufactured by Jaguar will be all-electric by 2025, and by Land Rover by 2036.[147]
- In 2022, BMW announced an aim to sell more than 2 million electric vehicles in 2025 and to have 50% of its vehicles be electric by 2030.[148]
- In early 2023, Google, Ford, and General Motors, along with solar energy producers in the United States, announced a partnership to develop virtual power grids.[149]

There is a risk of an electric mobility divide between high-income countries and low- and middle-income countries, in the absence of electrification policies tailored at the economic and regional context. Historically, high-income countries have been responsible for the majority of greenhouse gas emissions, and they therefore have a responsibility to help low- and middle-income countries with vehicle electrification and overall transport decarbonisation.[150]

- The priority of low- and middle-income countries should be on accessible, affordable, inclusive, secure and safe transport options – with a focus on formal transport, e-bikes, and two- and three-wheelers.
- In 2022, Angola passed a law to half the import duty and vehicle tax for electric vehicles.[151] Many other countries have set tight import regulations (*see Section 3.6 Road Transport*).
- Chinese Taipei donated 10 electric buses to Paraguay in 2023 to kickstart that country's electric public transport fleet.[152]
- Sudan is actively working on retrofitting tuk-tuks to be solar-powered electric vehicles.[153]

Partnership in action

- Through the **Accelerating to Zero Coalition**, established at COP 26 in 2021, more than 200 stakeholders – including governments, auto manufacturers, investors, financial institutions and fleet operators – committed to transition to 100% zero-emission cars and vans globally by 2040, and no later than 2035 in key markets.[154] Signatories also pledged to support emerging economies through technical assistance, finance and capacity building.[155]
- **EV100** – a global group of businesses committed to fleet electrification – has committed to deploying more than 5.5 million electric vehicles by 2030.[156]
- The **Electric Vehicle Initiative's EV30@30 campaign**, launched in 2017, set a goal of achieving 30% electric vehicle sales (including cars, buses and trucks) by 2030, with the support of 15 countries and more than 20 companies and organisations.[157]
- In 2021, 15 countries announced support for the **Global Drive to Zero Campaign**, committing to the first global Memorandum of Understanding on Zero Emissions Medium- and Heavy-Duty Vehicles, with the goal of achieving 2030 and 2040 targets for new electric truck and bus sales.[158] The signatories, representing around 5% of global medium- and heavy-duty vehicle sales, must report progress annually and develop plans to support their ambitions.[159]
- The **TUMI E-Bus Mission** assists 20 cities in creating world-leading electric bus fleets and scaling e-bus adoption to hundreds more through city-to-city mentorship.[160]
- The **Zero Emission Bus Rapid- deployment Accelerator (ZEBRA) Partnership** was established by C40 and International Council on Clean Transportation to accelerate the deployment of zero emission buses in major Latin American cities.[161]
- The **Zero Emission Vehicles Transition Council** was established by the UK COP26 Presidency as the world's first political forum to discuss how to accelerate the pace of the global transition to zero emission vehicles.[162] The forum consisted ministers and government representatives from the world's largest and most progressive automotive markets, collectively accounting for more than half of all new car sales globally.

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