ITF Transport Outlook 2019

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Editorial

The *ITF Transport Outlook 2019* presents scenarios for the future of transport for all sectors and modes until 2050. How will demand for transport develop over the next three decades? How will this affect transport CO_2 emissions? How could various disruptive developments affect transport? To what extent will transport's future resemble its past, and to what degree will it become something altogether different?

The level of uncertainty with regard to the future path of transport is striking in all its areas. Uncertainties surround the pace of economic development, global trade and the price of oil. Uncertainties abound regarding travel behaviour and mobility patterns as well as technological progress and innovations. The sheer multitude of variables and the enormous scope of increasingly fast-paced and disruptive change render the future of transport ever more difficult to foretell.

Past *ITF Transport Outlooks* have addressed "normal" uncertainty about the future. They offered scenarios in which the speed and direction of changes in transport would shift incrementally, not going as far as to considerer changes in the fundamental scope and structure of transport activity. This is a prudent starting point when transport as a social-technical system called transport is generally mature and stable.

Yet sometimes disruptions trigger developments that foreshadow of a future radically different from a mere extension of the present. It is at these times that extrapolation as the default approach for thinking about the future becomes less helpful. As a trend emerges, humans tend to underestimate its importance for the future. Conversely, they overestimate the future significance of an already mature development. Even as forecasts no longer align with reality, we remain overly optimistic. For example, projections of road traffic volumes in many countries have far exceeded real road usage.

Transport has undergone several disruptions in the past 300 years – from animal traction to machine traction, from sail to powered navigation, from coal to liquid fossil fuels. Indeed, today's transport systems is the result of disruption (notably of the introduction of the combustion engine), and it is not unreasonable to believe that by 2050 fundamental changes in the way people have access to work, to services, to goods, leisure and each other will occur.

A main focus of this *Transport Outlook* is an attempt to assess the impact of potential and plausible disruptions to the transport sector – and to do so in a robust way by stress-testing assumptions at the core of the different scenarios. Describing the effects of a disruption that has occurred is relatively straightforward. Identifying a disruption in progress is a different and more ambiguous exercise. For the purposes of this study, disruption is defined as innovations which lead to entirely new ways of doing things – or allow the previously impossible to occur.

Disruptions can occur at different levels and various scales. Some only impact one product category – the introduction of synthetic rubber production and its effect on the tyre industry or the uptake of mobile ticketing for public transport, for example. Others reshape an entire sector – such as centralised, computer-based ticketing for air travel or the arrival of app-based ride-sourcing for the taxi sector. Other disruptions still, though rare, have a broad impact across multiple sectors and areas of human activity – e.g. the mass production of cars and the resulting changes on travel behaviour, on urban development (and real estate markets), on opportunities and economic welfare in general. Another example is the introduction of the standardised shipping container and the significance this had for freight transport, hence trade, economic activity, and ultimately global income growth.

The analysis in this *Transport Outlook* centres on disruptions with the potential to entail broad and wide-spread changes to existing practices and areas of transport activity. Five core factors drive disruptive changes:

- *Cost*: new technologies and/or processes make old ones uncompetitive in terms of production costs – the new ones become so cheap that old ones become unprofitable.
- *Quality*: new technologies and/or processes raise the quality of products or services to a level that makes the old ones uncompetitive.
- *Customers*: significant changes in consumer or business customer preferences make previous products or services unattractive compared to new ones.
- *Regulation*: new laws or regulations no longer permit old ways of working – for example environmental or labour protection rules – or allow new ways of doing things that previously were not allowed.
- *Resources*: previously important resources are no longer readily available or previously inexistent or inaccessible resources now become available.

Disruptive trends typically emerge from a combination of these factors. For instance, a change in cost combined with an improvement in quality or the convenience of a technology or service may change consumer perception of value for money, which then motivates the adoption of a new good or service. Indeed, many disruptive technologies or services are not necessarily superior to existing ones but simply provide “good enough” functionality at a low cost.

Much of the discourse around innovation and disruption centres on technology because of the facilitating role the latter plays. But technology alone does not cause or sustain the types of radical changes it can trigger. Further, many disruptions are aided by the parallel emergence of multiple technologies and the services they facilitate. In this respect, disruptions can better be characterised as *disruptive developments,* which – in combination with other factors and under the right facilitating conditions – can lead to change that makes previous processes, services and/or products ineffective.

Transport today is a socio-technical ensemble that converges towards a central set of technologies and practices. These practices evolve together into a stable, self-reinforcing system. Innovations branch out at the margin of this central strand, but few gain enough traction to change the overall momentum and trajectory of the system. Under the right set of conditions a few innovations may gain hold, however. As innovators start to nudge the system away from its path, some incumbent firms, existing services or established behaviours are no longer viable. Some fail while others adapt and accompany the early disrupters – some in earnest, others to hedge their bets.

In periods of disruption, the historical system starts unbraiding itself and a patchwork of multiple, sometimes conflicting, socio-technical regimes emerges. This patchwork includes legislation and regulation, behaviours and activities, and technologies and services. The period of disruptive unbraiding and transitional re-weaving is characterised by high levels of uncertainty. Early disruptors still act in reference to the historic strand of the socio-technical system. But at some point during the transition new players appear that no longer reference the old set of actors, rules and practices. At this stage, convergence towards a new socio-technical regime sets in.

Clearly, there are developments within and outside of the transport sector today that are challenging the existing ways of doing things. The arrival of digital platforms that are giving rise to new mobility services, the change in shopping as a result of e-commerce and the (potential) decentralisation of production as a result of 3D printing may have a significant impact on passenger and freight transport.

But how much of an impact? The answer to that question partially lies in how public authorities position themselves vis-à-vis such developments. What rules do governments remove, which rules do they put into place? Which trends support political mandates, say, for more efficiency, increased sustainability, enhanced equity? And which disruptive developments might on the contrary undermine societal objectives?

The analysis presented here does not, and cannot, answer these questions directly, and the scenarios in this *Transport Outlook* should not be taken as forecasts for the coming 30 years. Rather, they describe several possible futures. Whether reality comes closer to one or the other will depend on how assumptions for the scenarios hold up, and also on the course of action policy makers will chose. What this study offers are plausible scenarios around future disruptions that can inform discussions about the role public policy can play in guiding and managing disruptive change.

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Chapter 2. Impact of transport policies on CO2 emissions to 2050	Katherine Farrow and Jari Kauppila
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Katherine Farrow co-ordinated the editorial process of the report. Statistical and research assistance was provided by Ashley Acker and Mario Barreto. Michael Kloth edited the report and supervised the publication process, Edwina Collins copy-edited the manuscript and Ana Cuzovik designed several visual elements included in the publication. The team also thanks for the help provided by colleagues of ITF for their valuable comments: Olaf Merk for his participation in the freight chapter, Jagoda Egeland for her participation in the non-urban passenger chapter, Katja Schechtner on drones, and Wei-Shiuen for her contributions to material on the electrification of personal mobility. The modelling approach was inspired by Andreas Shaffer (University College of London), Lóránt Tavasszy (Delft University of Technology) and Alan McKinnon (Kühne Logistics University). The ITF also benefited from the help provided by the following bodies of the OECD: the Environment Directorate for the trade projections and the International Energy Agency for their knowledge and model on vehicle and fuel technology (Mobility Model). Several partners have been valuable developing the ITF modelling framework, methodologies and providing data: The International Council for Clean Transportation (ICCT) for data on local pollutant emissions; The International Maritime Organization (IMO) for data on vessel fleet composition and vessel speed data; The Energy and Resources Institute India, (TERI), China Academy of Transportation Sciences, Japan International Cooperation Agency (JICA); Economic Commission for Latin America (ECLAC) and Development Bank of Latin America (CAF) for data on Latin American cities and trade; the Road Freight Lab of World Business Council on Sustainable Development (WBCSD) on the freight optimisation; and the International Civil Aviation Organisation (ICAO) and the Airport Council International Europe (ACI Europe) for their help with aviation forecasts and emissions. Finally, the *ITF Transport Outlook 2019* benefited from valuable comments from the members of the Transport Research Committee, which also approved the report.

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Teleworking	Urban passenger
Ultra-high-speed rail	Non-urban passenger
Long-haul low-cost air carriers	Non-urban passenger
Energy innovations in aviation	Non-urban passenger
E-commerce	Freight
High-capacity vehicles	Freight
3D-printing	Freight
Energy transition in long-distance road freight	Freight
Changing international trade routes	Freight
Autonomous vehicles	Urban passenger, Freight

Mitigation measures	Sector
Public transit integration and expansion	Urban passenger
Mobility as a service (MaaS)	Urban passenger
Parking pricing	Urban passenger
Car access restrictions	Urban passenger
Land-use policies to increase urban density	Urban passenger
Improved freight logistics	Freight
Lower coal and oil consumption	Freight
Efficiency improvements and electric vehicles	Urban passenger, Non-urban passenger, Freight
Carbon pricing	Non-urban passenger, Freight
Logistics efficiency	Freight
International coal and oil consumption	Freight

3D printing	An additive printing technology that creates 3D products through the successive addition of very thin layers of material.
Active transport modes	Travel undertaken by foot, bicycle, other human-powered mode.
Air connectivity	The density, extensiveness, and directness of destinations in a transport network.
Autonomous vehicle	A vehicle operated by a driving system that either assists or replaces humans in the driving task. Automation can be of different degrees according to the portion of the operations the driving system can conduct without human intervention.
Biofuel	Fuels that are directly or indirectly produced from organic material, i.e. biomass, such as plant materials or animal waste. In this publication, biofuel refers to liquid biofuels, such as ethanol or biodiesel.
Bulk ship (bulkers)	Ships transporting goods in unpackaged bulk, such as grains, coal, ore or cement.
Bus rapid transit (BRT)	Buses running in lanes separated from the general traffic, with high standards of quality of service, in particular regarding frequency and reliability.
Car	A road motor vehicle, other than a moped or a motorcycle, primarily designed to carry one or more persons. This includes SUVs and is equivalent in the text to passenger light duty vehicles (PLDVs).
City	Used as a generic term to designate all urban agglomerations. The boundaries of a city in the Outlook tend to go beyond administrative boundaries (see *Urban agglomeration*).
Congestion	The relative travel time loss at the peak traffic hour on the road network due to slower travel speeds.
Container ship	A ship fitted throughout with fixed or portable cell guides for the exclusive carriage of containers.
Current ambition scenario:	A scenario developed by the ITF that reflects the continued implementation of existing mitigation policies, as well as announced mitigation commitments. The scenario includes potentially disruptive developments in the transport sector at current (i.e. non-disruptive) levels and technological assumptions that are broadly in line with the IEA's New Policies Scenario.
Dockless	See free-floating.
Domestic inter-urban transport	All passenger and freight transport activity within a country, excluding transport that takes place in cities.
Drones	Remotely- or autonomously-piloted airborne vehicles capable of transporting freight or passengers.
E-commerce	The sale or purchase of goods or services, conducted over computer networks by methods specifically designed for the purpose of receiving or placing orders.
Electric road system (ERS)	A road stretch equipped with infrastructure that enables vehicles to receive electricity while moving via overhead catenary, ground conductive or inductive technologies.
EV30@30 Scenario	A scenario used in the IEA's Global EV Outlook (2018) that assumes the rapid electrification of global vehicle fleets such that electric vehicles comprise 30 percent of new car sales by 2030.
Free-floating	A free-floating, or dockless, shared vehicle system that has no set stops or infrastructure. These services rely on a combination of GPS and cellular connectivity to track rented vehicles, charging time-based usage fees, and locking the device when it is left at the end of its trip.
Free-flow speed	The average speed a vehicle can travel according to road type, assuming no congestion or other constraints (traffic lights, weather conditions etc.).
Freight transport demand	A measure of the volume of freight travel, measured in tonne-kilometres.
High ambition scenario:	A scenario developed by the ITF that reflects the full deployment of known mitigation measures at levels that are more ambitious than current levels, along with announced mitigation commitments. The scenario includes potentially disruptive developments in the transport sector at current (i.e. non-disruptive) levels and technological assumptions that are broadly in line with the IEA's EV30@30 Scenario.
High capacity vehicle (HCV)	vehicles that exceed the general weight and dimension limitations set by national regulations and are usually operated within limited geographical areas or on specific routes under special provisions.
Hydrogen fuel cell technology	Converts hydrogen stored in fuel cell batteries to electricity to power vehicle movement.
Hyper-loop	Trains that use magnetic levitation technology and travel inside reduced-pressure tubes, capable of reaching speeds of up to 1200km/h.
Liquefied natural gas (LNG)	Gas consisting mainly of methane, which is converted to liquid form by reducing its temperature to 160°C under atmospheric pressure.
Local pollutants:	Elements of ambient air pollution, including emissions of mono-nitrogen oxides (NOx), sulphate (SO4) and fine particulate matter (PM2.5).
Low-cost carrier	Airline which offers lower fares in exchange for lower comfort. Cost-cutting practices include streamlined aircraft fleets, limited destinations, capacity maximisation, and charging additional fees for extra services.
Maglev	Trains that use magnetic levitation technology and capable of reaching speeds of up to 500 km/h.
Mass transit	Bus rapid transit (BRT) or urban rail (metro included).
Mega-ship	Very large container ship with a capacity larger than 13 000 TEU.
Mobility as a service (MaaS)	Digital platforms that enable demand-responsive route optimisation across modes, including dockless micro-mobility modes.

Mode split/modal share	Percentage of total passenger-kilometres accounted for by a single mode of transport; percentage of total freight tonne-kilometres accounted for by a single mode.
Mode	Refers to the method of transport service: e.g. road, rail, waterway, air or private car, powered two-wheelers, bus, metro, or urban rail.
Motorcycle	Powered two-wheeled vehicles, motorcycles and scooters, equivalent in this text to two-wheelers.
New Policies Scenario	The New Policies Scenario serves as the IEA baseline scenario. It takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be determined.
On-demand transport	Transport services that do not follow a fixed route or schedule and can be requested (typically via digital platforms) to undertake bespoke trips either immediately or at a pre-determined time.
Passenger transport demand	A measure of the volume of passenger travel, measured in passenger-kilometres.
Passenger-kilometre (p-km)	Unit of measurement for passenger transport activity representing the transport of one passenger over a distance of one kilometre.
Private transport modes	Private motorised vehicles or taxis.
Public transport modes	Bus, metro, tram, and rail.
Revenue passenger-kilometre	A measure of passenger traffic expressed as the number of paying passengers multiplied by the number of kilometres flown.
Shared transport modes	Includes motorised and non-motorised modes (e.g. shared conventional or electric bikes and cars), traditionally shared vehicle systems (where travellers share the same vehicle at different points in time, e.g. free-floating or non-free-floating shared cars or bikes) and optimised shared mobility (where travellers share the same vehicle, e.g. a shared taxi or minibus with a driver (Shared taxi and taxi-bus, respectively, in the ITF's shared mobility work), at the same time for at least part of their trip).
Shared mobility service	An optimised shared-vehicle fleet system (e.g. shared taxis or minibuses with a driver) that provides on-demand transport and is typically enabled by an app-based digital platforms; travellers share the same vehicle at the same time for at least part of their trip.
Surface freight transport modes	Freight transport modes including road, rail, inland waterways (excluding sea and air).
Synthetic fuel	Created through chemical processes that combine carbon monoxide and hydrogen to produce products such as gasoline and jet fuel.
Tankers	Ships transporting liquid cargo, especially oil and oil products.
Teleworking	Carrying out work at a location that is remote from the employer's office while staying connected to the office via network technologies.
Twenty-foot equivalent unit (TEU)	A statistical unit based on a standard (ISO) 20 ft (6.10 m) container that describes the capacity of container ships or terminals. One 20-foot ISO container equals one TEU.
Three-wheeler	Powered three-wheeled vehicles, such as auto-rickshaws in India.
Tonne-kilometre (t-km)	Unit of measurement of goods transport which represents the transport of one tonne of goods over a distance of one kilometre.
Transit-oriented development	A dense development with access to public transport in walking distance and characterised by a mix of residential, employment, commercial and other uses.
Two-wheelers	Powered two-wheeled vehicles, motorcycles and scooters; equivalent in this text to motorcycles.
Urban agglomeration	The city and surrounding areas of contiguous built-up land.
Vehicle-kilometre (v-km)	A unit of measurement for freight and passenger transport demand that represents the movement of a single vehicle over a distance of one kilometre.

Executive summary

Background

The *ITF Transport Outlook* provides an overview of recent trends and near-term prospects for the transport sector at a global level, as well as long-term projections for transport demand to 2050. The analysis covers freight (maritime, air, surface) and passenger transport (car, rail and air) as well as related CO_2 emissions, under different policy scenarios.

A specific focus of this edition is the impact of potential disruptions to transport systems. How will disruptive developments impact future demand, modal shares and transport-related CO_2 emissions? Emerging transport trends such as electrification, shared mobility and autonomous vehicles could have profound implications for the sector and for setting policy, as could exogenous developments such as e-commerce, 3D printing or new international trade routes.

A broad range of disruptive scenarios were simulated for this report. These scenarios were designed in order to explore the boundaries of realistic assumptions regarding future conditions. As a result, these findings describe a set of possible futures based on extreme assumptions; they are not forecasts for the next 30 years. Whether reality comes closer to one or the other will depend on the extent to which the assumptions materialise as well as on the course of action that policy makers choose to take in the coming years. The purpose of these simulations is to inform discussions about the role that public policy can play in guiding and managing disruptive change.

Findings

Uncertainty is a defining feature of the current economic climate and this limits the ability to make robust projections. Still, it can be stated with some confidence that, globally, demand for mobility will continue to grow over the next three decades. Passenger transport will increase nearly three-fold between 2015 and 2050, from 44 trillion to 122 trillion passenger-kilometres. China and India will generate a third of passenger travel by 2050, compared with a quarter in 2015.

Private vehicles will remain the preferred mode of personal travel worldwide. Travel in cities especially will shift towards public transport and shared mobility. By 2050, both these modes are projected to account for over 50% of total passenger-kilometres. International passenger travel is increasing globally, and growth is projected to be strongest in developing countries. Aviation passenger-kilometres in India and China alone are expected to increase almost four-fold by 2050, to 21 583 billion from an estimated 5 506 billion in 2015.

Global freight demand will triple between 2015 and 2050 based on the current demand pathway. At 4.5%, air freight is expected to have the highest compound annual growth rate of all modes through 2050, although representing a small share of total freight tonne-kilometres. More than three-quarters of all freight will continue to be carried by ships in 2050, more or less unchanged from 2015. In light of current challenges to the global economy and burgeoning trade conflicts, the accuracy of projections for freight transport is particularly uncertain, as demand depends primarily on economic growth and international trade activity.

Transport CO_2 emissions remain a major challenge. The extrapolation of current policy ambitions into the future shows that these will fail to mitigate increases in transport CO_2 emissions in the face of strong growth in transport demand over the coming years. In a scenario where current and announced mitigation policies are implemented, worldwide transport CO_2 emissions are projected to grow by 60% by 2050. This growth is driven mainly by increased demand for freight and non-urban passenger transport, both of which are projected to grow 225% by 2050. Emissions from urban passenger transport, in contrast, are projected to fall by 19%, reflecting existing strong focus of current policies on urban transport.

The implementation of more ambitious decarbonisation policies significantly alters the projected pathways for transport demand and related CO_2 emissions. In such a high ambition scenario, global demand for passenger transport would be 20% lower in 2050, and related emissions 70% lower, relative to a current ambition scenario. Although global demand for freight transport would remain relatively stable in both scenarios, carbon emissions from freight transport would be 50% lower in 2050 relative to a current ambition scenario. Yet even this would fail to deliver the reductions required to achieve the Paris Agreement objective of maintaining the average global temperature increase to well-below 2 degrees Celsius above the pre-industrial era.

Transport faces a number of potential disruptions from within and outside the transport sector. The impacts of such developments, individually as well as combined, were modelled for this *Transport Outlook.*

Shared mobility could halve the number of vehicle-kilometres travelled in urban areas if widely adopted. This could lead to a 30% decrease in CO_2 emissions from urban transport by 2050 relative to projections based on current ambitions. The widespread use of autonomous vehicles would likely increase the number of vehicle-kilometres travelled and tonnes of CO_2 emissions generated in most urban regions. Simulations indicate that more teleworking could decrease global urban passenger-kilometres travelled and related CO_2 emissions by around 2% in 2050 compared to the current ambition scenario.

Simulations indicate that the proliferation of long-haul low-cost aviation would increase the total number of passenger-kilometres travelled in non-urban transport and related CO_2 emissions by 1% in 2050 relative to current projections. Simulation results suggest that the availability of ultra-high speed rail systems would increase total rail ridership by 1% while reducing CO_2 emissions from non-urban transport by less than 1%. The use of alternative aviation fuels, in contrast, has the potential to dramatically reduce CO_2 emissions from air transport, essentially by making short-haul flights carbon-free. This could result in 55% fewer emissions from domestic aviation in 2050 relative to a current ambition scenario.

Rapid growth in e-commerce could lead to modest increases in freight volumes of between 2% and 11%, depending on the transport mode. Freight-related CO_2 emissions would increase by 4%. The large-scale uptake of 3D printing in manufacturing and for home use could reduce global freight volumes by 28% and related CO_2 emissions by 27%

compared to a current ambition scenario. This level of uptake in 3D printing is not particularly likely, however.

New trade routes would have a modest impact on global trade volumes, reducing them by 2% and related CO_2 emissions by 1% to 2050 relative to current projections. The development of new international trade routes, however, could significantly change existing spatial patterns of freight transport, which would have important implications for global logistics chains and transport network infrastructure.

With respect to surface freight transport, the widespread uptake of high capacity vehicles could lead to a 3% decrease in CO_2 emissions from freight transport in 2050 relative to current projections. The introduction of low- or zero-carbon fuels in long-distance road freight could lead to carbon reductions of 16% by 2050. Simulations indicate that the use of high capacity vehicles and autonomous trucks in road freight transport would not have significant impacts on overall demand for freight transport or freight-related emissions.

In full disruption scenarios, in which several disruptive developments coincide, projected transport demand and the related CO_2 emissions are lower in 2050 relative to the current ambition scenario in all sectors. The strongest emissions reductions can be achieved with policies in place to guide the disruptions. In urban passenger transport for example, the widespread adoption of shared and autonomous vehicles could cut CO_2 emissions by 73% and congestion by 24% in 2050 relative to current projections if managed by appropriate policies.

Similarly, technological disruptions in non-urban passenger transport have greater carbon mitigation potential when managed through complementary policy measures, rather than when they just occur. In the first case, they could reduce emissions by 76% in 2050, in the second by 63%. Outcomes are similar in freight transport, where policy measures to increase logistical efficiency augment the emissions reductions achieved by technological disruptions. Left to themselves, technological disruptions lower freight-related CO_2 emissions by 44% in 2050 compared to current projections. With the concurrent implementation of logistical policy measures, emissions reductions reach 60%.

Taken together, the simulations show that transport policies heavily determine the impact that disruptions will have on the demand for transport demand and on its carbon footprint. The simultaneous implementation of policies designed to mitigate the negative impacts of disruptions enhances emissions reductions in all sectors of transport. Thus, policy makers have a crucial role to play in determining the nature and extent of change even where developments stand to disrupt transport systems considerably.

Policy insights

Better planning tools improve adaptability to uncertainties

Long-term uncertainty complicates planning. This is especially the case for long-lived infrastructure investments. Scenario planning helps policy makers understand the bounds of decision sets and allows them to select options that are most robust to the greatest number of possible and plausible futures. Another strategy for decision-making under uncertainty is to design transport systems in ways that keep these systems adaptable to changing conditions, including the impacts associated with potentially disruptive developments.

Transport policy must anticipate disruptions that originate outside the sector

Transport policies must be able to respond to a broad range of disruptive developments. Only this will make it possible to reap potential benefits and minimise negative impacts. Disruptions from outside the transport sector are not under the control of policy makers. Their decisions determine the direction and magnitude of the impacts for the sector, however. Smart policies take into account how disruptions affect incentives for transport users and avoid incentive structures that generate undesirable outcomes. Data will be paramount in better understanding the dynamics and potential impact of developments that could disrupt transport.

Transport systems will benefit from policy frameworks that foster innovation

Innovative technologies and new business models are at the heart of the disruptive developments that transport faces. The speed with which both change often outstrips the pace at which regulation adapts. Thus public authorities will need to move away from the traditional static approach. Rather, the transport system would benefit from frameworks that allow experimentation and iterative changes. Frequent regulatory reviews, limited regulatory exemptions and collaborative regulation-building involving public authorities and regulated entities can all play a role. Robust risk assessment is necessary to determine when these approaches can be safely adopted without jeopardizing desired policy outcomes.

More ambitious policies are needed to stop the growth of transport CO_2 emissions

All policy levers will need to be used to deliver transport solutions that meet increasing mobility demand in sustainable ways. These must aim to avoid unnecessary transport demand, shift mobility to sustainable transport options and improve the efficiency of transport. Many current policies focus on urban transport, and with some success. They now also need to address the still-growing emissions in non-urban and international transport.

Chapter 1. How transport demand will change by 2050

This chapter examines past trends in transport demand and offers projections of future transport activity to 2050. It first reviews the key drivers for recent trends in transport demand and for expected developments. Demand projections for passenger transport are broken down for urban, domestic and international transport by mode. Freight projections are presented for maritime, surface, and air freight transport.

Increasing uncertainty about the drivers of transport demand

Uncertainty is a defining feature of the current economic climate and impact the ability to make robust projections. Among the unpredictable factors are the potential for increasingly bilateral international trade relationships, supply-driven disruptions in oil prices, and tighter financial conditions in emerging economies (OECD, 2018[1]). The combined downside impact of these factors could reduce the level of global output by over 0.5% in 2020 relative to baseline projections of the Organisation for Economic Cooperation and Development (OECD, 2018[1]). This would certainly attenuate growth in demand for transport, especially freight.

Transport demand is nevertheless expected to grow significantly in the coming years. This will be the case especially in developing countries. Population, gross domestic product (GDP) and international trade activity have been strongly correlated historically with global transport demand and will continue to determine demand.

Population growth drives transport demand because more passengers require more mobility. A larger population also implies increased production and consumption of goods, thus raising the demand for freight transport. Shifting population densities also affect transport demand by changing its distribution. Populations around the globe are becoming increasingly urbanised, even as overall demographic growth decelerates in most regions.

The average distance travelled by both people and freight rises as disposable income grows, and this increases the demand for passenger and freight transport respectively. The reciprocal relationship between economic activity and transport activity has resulted in a strong statistical correlation between GDP and transport demand (Banister and Stead, 2002[2]). For instance, growing per capita GDP tends to increase private vehicle ownership, an effect that is strongest for middle income ranges and weaker at the lowest and highest income levels (Dargay, Gately and Sommer, 2007[3]). Increasing sub-urbanisation in the wake of expanding urban populations also boosts private vehicle ownership. Although transport demand remains relatively closely linked with GDP, some work suggests that a decoupling of passenger transport from GDP has begun in developed countries (IPCC, 2014[4]); (IEA, 2018[5]); (Girod, van Vuuren and Hertwich, 2013[6]).

Freight transport enables the movement of intermediate and finished goods and thus strongly correlates with levels of international trade. To the extent that manufacturing and trade activity are sensitive to freight costs, oil prices also play an important role for determining freight demand. International trade has continued to grow modestly compared to growth rates prior to the 2008 economic downturn. This trend can be partly explained by cyclical factors in the wake of the downturn, but structural factors also play a role. Trade in services, for instance, increased from 23% to 30% between 2005 and 2017 (UNCTAD, 2018[7]), the elasticity of trade to GDP has declined (WTO, 2018[8]) and the expansion of global value chains has begun to slow (WTO, 2017[9]).

Trade liberalisation has also been slower since 2007 (OECD, 2016[10]). Growth in international trade nevertheless picked up in 2017 mainly due to increased consumption and investment spending and becausethe elasticity of trade to GDP rebounded towards pre-crisis levels. The current outlook for international trade is broadly positive, but a range of downside risks could undermine this development (WTO, 2018[11]). Notably, recent political developments have led to increased protectionism in 2018. An ever-higher proportion of value-added activity coming from financial capital flows and the increased concentration of trade activity carried out by large corporations heightens exposure of the world economy to future economic downturns (UNCTAD, 2018[7]).

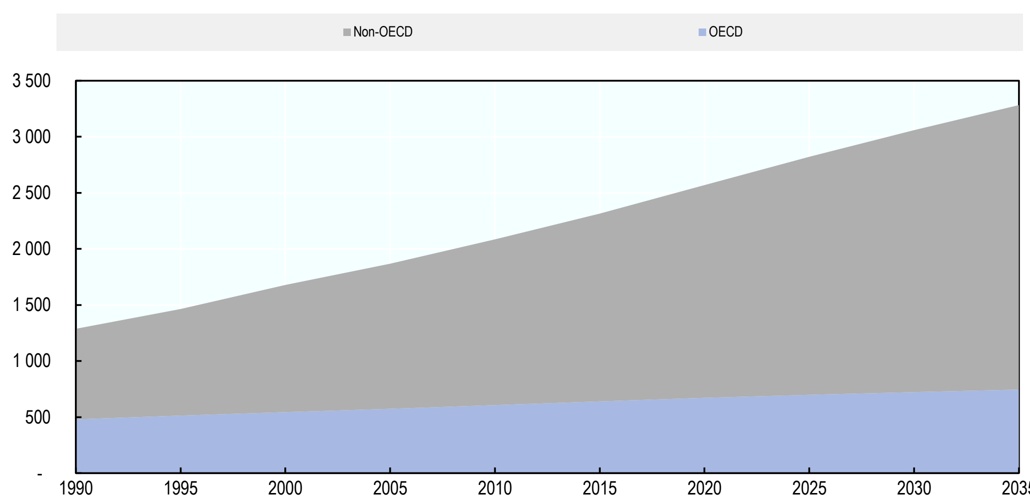
A changing world demographic

Freight and passenger mobility demand will grow as the global population continues to expand, particularly in cities. Today's world population of 7.7 billion people (as of January 2019) is predicted to grow to 8.5 billion by 2030 and 9.7 billion by 2050 (Bank, 2017[12]). In 2018, 54% of the global population resided in urban areas. By 2050, this figure is expected to rise to 68%, and as many as ten new mega-cities of more than 10 million people are expected to appear in the next twenty years (UN DESA, 2018[13]).

Urbanisation rates will be particularly high in emerging and developing economies. Much of the anticipated increase in the global population by 2050 is projected to occur in Africa and in countries with large populations such as India, Pakistan, and Indonesia (Bank, 2017[12]). By 2100, Africa will be home to as much as 40% of the world population.

Figure 1.1. Population of cities with over 300 000 inhabitants

Million inhabitants



Source: UN DESA (2018[13])

StatLink http://dx.doi.org/10.1787/888933971974

Slowing economic growth

Economic growth plays a central role for the development of transport demand. The latest composite leading indicators of global GDP growth rates show a slowing momentum (OECD, 2018[14]). Previous optimistic projections for GDP growth have been revised downwards in light of political and economic developments. Global GDP growth is now projected at 3.5% in 2019 and 2020 (Table 1.1). The estimated compound annual GDP growth rate for 2015 to 2030 is 3.3%, with slightly slower growth of 2.9% projected for longer term scenario of 2015 to 2050.

Trends diverge between world regions. One the one hand, developing economies will continue to grow at high rates, despite the expected deceleration of the global economy.

This will make them the main drivers of growth for future transport demand. GDP growth rates of emerging market and developing economies will stabilise at 4.7% in 2019/20. China's growth rate will decline from nearly 7% in 2017 to 6% by 2020, and India's GDP growth rate should fluctuate around 7.4% in the next couple of years – making it the country with the highest growth rates world-wide for 2018-20 (OECD, 2018[1]). GDP growth rate for OECD countries, on the other hand, will decrease gradually over the coming years, reaching 1.9% by 2020. In the United States, the 2018 GDP growth rate was nearly 3%, partly supported by the recent fiscal stimulus packages (OECD, 2018[1]).

Factors contributing to the slower economic expansion include geopolitical instability, increased protectionism, as well as the ramifications of trade tensions on employment and business confidence. Inflation could increase steeply with rising oil prices and new trade tariffs. High levels of public and private debt increase the financial vulnerability of many countries and could further hinder economic growth. The downward trend in productivity levels and a shrinking workforce due to aging populations can constrain expansion in advanced economies (IMF, 2018[15]); (OECD, 2018[1]).

Business-level data supports predictions of lower growth. The year-on-year global growth rates of both industrial production and retail sales volume have declined noticeably in the first three quarters of 2018, accordig to preliminary data. Manufacturing export orders has been decreasing steeply throughout the year (OECD, 2018[1]).

Table 1.1.GDP growth in world regions

Percentage change over previous year

						Compound Annual Growth Rate	
	2016	2017	2018*	2019*	2020*	2015-2030*	2015-2050*
OECD							
World	3.1	3.6	3.7	3.5	3.5	3.3	2.9
OECD countries	1.8	2.5	2.4	2.1	1.9	2.0	1.9
Euro Area	1.9	2.5	1.9	1.8	1.6	1.5	1.6
United States	1.6	2.2	2.9	2.7	2.1	1.8	1.9
Japan	1.0	1.7	0.9	1.0	0.7	1.0	1.1
Non-OECD countries	4.2	4.6	4.7	4.7	4.7	4.2	3.5
Brazil	-3.4	1.0	1.2	2.1	2.4	2.2	1.9
China	6.7	6.9	6.6	6.3	6.0	4.8	3.2
India	7.1	6.7	7.5	7.3	7.4	6.5	5.2
World Bank							
World	2.4	3.1	3.1	3.0	2.9	—	—
Advanced economies	1.7	2.3	2.2	2.0	1.7	—	—
Emerging market and developing economies	3.7	4.3	4.5	4.7	4.7	—	—
IMF							
World	3.7	3.7	3.7	3.7	—	—	—
Advanced economies	1.7	2.3	2.4	2.1	—	—	—
Emerging market and developing economies	4.4	4.7	4.7	4.7	—	—	—

Note: * Figures for 2018 onwards are predictions. World Bank figures for 2017 are estimates.
Source: OECD (2018[16]); World Bank (2019[17]); and IMF (2018[18]). Estimates for 2015-2030 and 2015-2050 are based on OECD ENV-Linkages model.

International trade faces uncertainties

Trade is a main determinant of freight demand. Current estimates show global trade growing slightly stronger than GDP, but on a downward path. The OECD ENV Linkages modelprojects 3.4% annual growth through 2030 and 3.2% through 2050 (Table 1.2) Global merchandise trade volumes are expected to grow at gradually descending growth rates from 2017 onwards, reaching 3.7% in 2019. The figures for merchandise trade growth reflect the risks of gowing protectionism that will not only reduce trade flows, but diminish the exchange of information and new technologies - with important impacts on productivity and long-term growth (WTO, 2018[11]); (IMF, 2018[15]).

Growth in trade will be impacted by the trend of global value chains becoming more consolidated (ITF, 2017[19]). Trade in emerging economies is also likely to be affected by market disturbances such as rising interest rates in developed economies (WTO, 2018[11]). Nevertheless, exports and imports will grow faster in emerging economies than developed economies. The compound annual growth rate of imports for developing and emerging economies will be 60% higher than that of developed economies for imports and nearly three-quarters higher for exports by 2050. Among the world regions, Asia displays the highest growth rates in merchandise trade. Although they are expected to slow as early as 2019, Asia will also grow fastest in the long-term through 2050 - together with South and Central America, according to OECD projections.

Table 1.2. World merchandise trade

Percentage change over previous year

					Compound Annual Growth Rate	
	2016	2017	2018*	2019*	2015-2030*	2015-2050*
World	1.8	4.7	3.9	3.7	3.4	3.2
Exports						
Developed economies	1.1	3.4	3.5	3.3	2.7	2.3
Developing and emerging economies	2.5	5.3	4.6	4.5	4.2	4.0
North America	0.6	4.2	5.0	3.6	3.5	2.8
South and Central America	2.0	3.3	2.8	2.6	3.1	3.4
Europe	1.2	3.5	2.9	3.2	2.2	2.0
Asia	2.3	6.7	5.5	4.9	4.2	3.8
Other regions	3.4	0.2	2.6	3.6	3.6	4.2
Imports						
Developed economies	2.1	3.0	3.2	3.0	2.7	2.5
Developing and emerging economies	1.6	8.1	4.8	4.5	4.3	4.0
North America	0.0	4.0	4.3	3.6	2.8	2.9
South and Central America	-6.7	4.0	3.6	4.0	4.3	3.9
Europe	3.3	2.5	3.1	3.0	2.4	2.1
Asia	3.5	9.8	5.7	4.9	4.2	3.9
Other regions	-1.7	3.5	0.5	1.4	3.6	3.7

Notes: *Figures for 2018 onwards are projections. Figures for 2015-2030 and 2015-2050 are based on the OECD ENV linkages model
Source: WTO (2018[11])

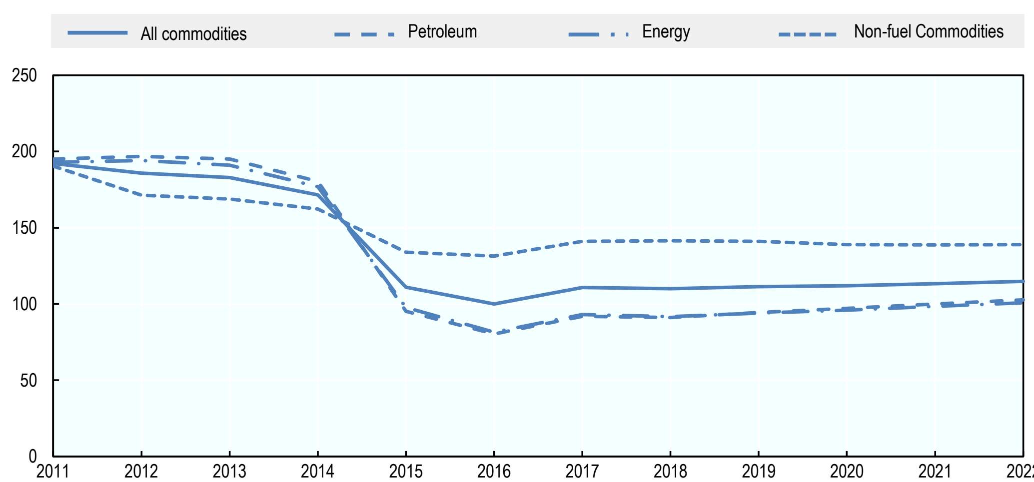
Uncertainty around oil prices

Rising oil prices could attenuate projected economic growth in the next few years by contributing to inflation and reducing disposable household incomes. Oil price fluctuations have a particularly significant impact on the transport sector. They can lead to shifts in transport behaviour and also in investment in renewables, two determinants of transport demand and transport-related CO_2 emissions. Transport CO_2 emissions in Europe decreased for the first time in 2007, which coincided with a spike in oil prices. As oil has become cheaper since 2012, transport emissions have started to grow again.

Driven mainly by increasing oil and natural gas prices, the International Monetary Fund's Primary Commodities Price Index grew nearly 17% from August 2017 to February 2018 (IMF, 2018[15]). The IMF sees fuel price increases to slow in the medium-term, however (Figure 1.2). Such price changes do not affect all world regions in the same degree, particularly since a weak USD can counteract high oil prices in some countries. Supply disruptions following natural disasters - notably the hurricanes on the US Gulf Coast and wildfires in Canada - contributed to recent oil prices hikes (EIA, 2017[20]). Political disputes have also led to longer and more severe disruptions in oil supply. Logistics issues, oil quality problems, and growing demand for liquefied natural gas also help to explain why global oil supply in 2017 fell to its lowest level since January 2012 (EIA, 2017[20]); (Lawler and Cooper, 2018[21]).

Figure 1.2. Primary commodity price indices, 2011-22

Constant USD, 2005 =100



Note: Figures for 2017 to 2022 are projections. Petroleum refers to petroleum crude spot: the average spot prices for Brent in the United Kingdom, Dubai and West Texas Intermediate.
Source: IMF (2019[22])

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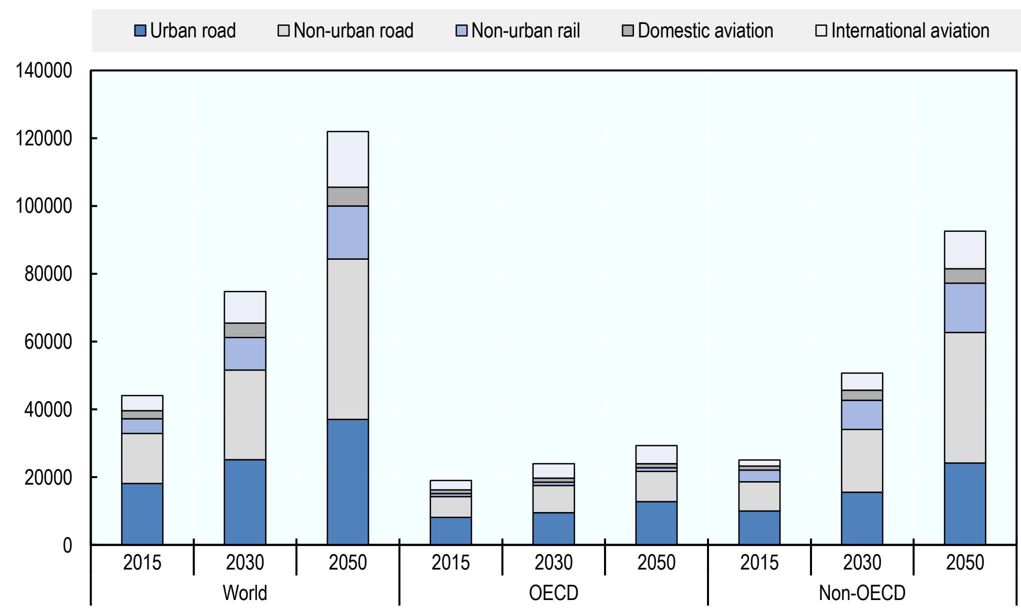
Growing demand for passenger transport

Demand for passenger transport is projected to grow in all world regions. It will increase three-fold between 2015 and 2050, from 44 trillion to 122 trillion passenger-kilometres (p-km), according to ITF projections (Figure 1.3). The distribution of demand will change siginficantly. OECD countries were responsible for 43% of global passenger movements in 2015, but their share will decline to 24% by 2050. The reason is the comparatively faster growth rates of passenger transport demand in other countries. China and India were responsible for a quarter of passenger-kilometres in 2015, but will generate one-third of passenger travel by 2050.

Non-urban rail passenger transport is expected to grow faster than all other mode groups by 2030. It will see annual compound growth of 5.5%, followed closely by international aviation at 5.0%. Demand for aviation and rail transport will continue to grow strongly through 2050, with compound annual growth rates of 3.8% and 3.7% respectively. Non-urban road passenger transport will more than triple by 2050, generating more passenger-kilometres than any other mode group, namely 47 trillion passenger-kilometres.

Figure 1.3. Demand for passenger transport by mode

Current demand pathway, billion passenger-kilometres



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Changing urban mobility patterns

Higher per capita income is typically associated with with an increased demand for passenger transport. By 2050, urban regions are expected to account for 81% of global GDP, up from 60% in 2015. Cities in developing countries will see incomes rise faster than anywhere else. Average GDP per capita will nearly quadruple in China (+296%) by 2050 and more than quintuple in India (+432%). As a result, global demand for urban passenger transport demand will more than double by 2050.

Much of this increase will likely be absorbed by shared mobility and public transport. Projections see shared mobility as the fastest growing transport mode in urban areas, while vehicle use will decline by 2030 (Figure 1.4). The urban passenger transport model used in this *Transport Outlook* has been modified from the 2017 version to include shared mobility (shared bikes, scooters, cars, taxis and buses) in the current ambition scenario, drawing upon the measurable impact that these services have already had on passenger transport movements.

Urban transport demand will grow particularly strong in non-OECD countries. Passenger-kilometres will reach 2.4 times their current levels by 2050 (24 trillion p-km), at which point they will generate twice as many passenger-kilometres as OECD countries. In 2050, the world's cities will generate 10 trillion passenger-kilometres by bus and bus rapid transit (BRT), 9 trillion p-km by private car, 8 trillion p-km from shared mobility, 4 trillion p-km by motorcycles, 3 trillion p-km by rail and metro, and less than 1 trillion p-km from non-motorised modes.

Shared mobility was only responsible for 1.5% of worldwide urban p-km in 2015, but by 2050 it is likely to cover more than one fifth of urban trips. Demand for shared mobility will be slightly higher in OECD countries (24%) than in non-OECD countries (20%).

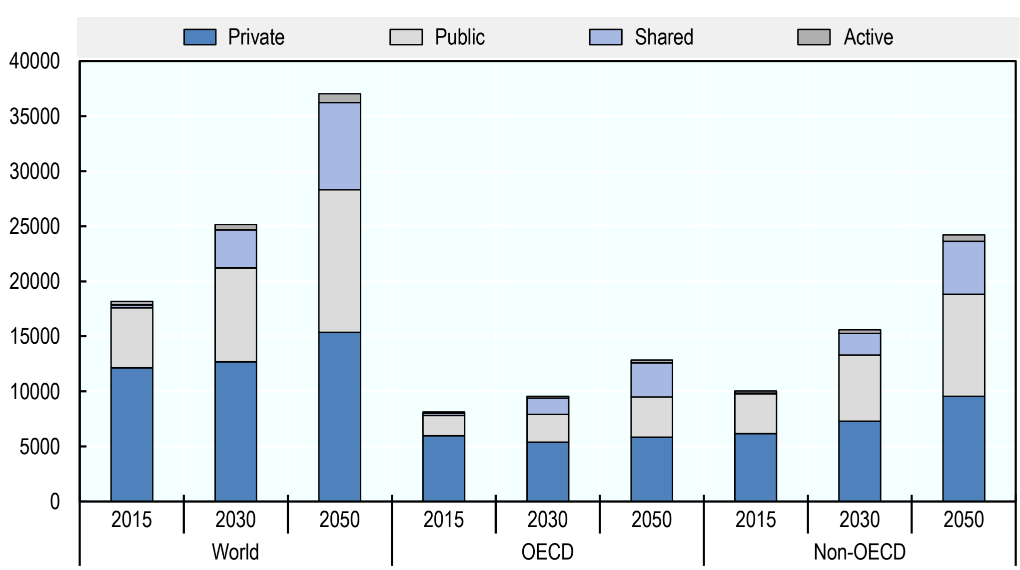
Private vehicles are currently the preferred mode of travel worldwide. However, evidence suggests that travel modes in cities will shift towards public transport and shared mobility over the next 35 years. Private cars, two- and three-wheelers and taxis are currently used for nearly 75% of urban passenger transport in OECD countries and over 60% in non-OECD countries. These shares will decrease to 46% and 39% by 2050. Projections suggest negative composite annual growth rates for private car ridership in cities through 2050 for OECD countries and through 2030 for non-OECD countries.

Public transport will account for 35% of worldwide urban passenger transport by 2050, that is 2.4 times more than in 2015. Public transport ridership will increase through 2030 and 2050 regardless of region. Particularly strong growth is expected for rail and metro in non-OECD countries (4.7% per year). Demand for bus and BRT transport should see an annual compound growth rate of nearly 2%, even if past trends in bus and coach travel diverge among some developed economies (Figure 1.5).

The growing use of public transport in urban areas of developed economies is partly due to the inability of existing road networks to accommodate increased travel demand. Congested roads mean greater levels of pollution and increased infrastructure maintenance. Public transport systems can improve accessibility and reduce CO_2 emissions and thus respond to growing passenger transport demand in urban regions.

Figure 1.4. Urban travel by mode group

Current demand pathway, billion passenger-kilometres



Note: See glossary for further information on mode groupings.

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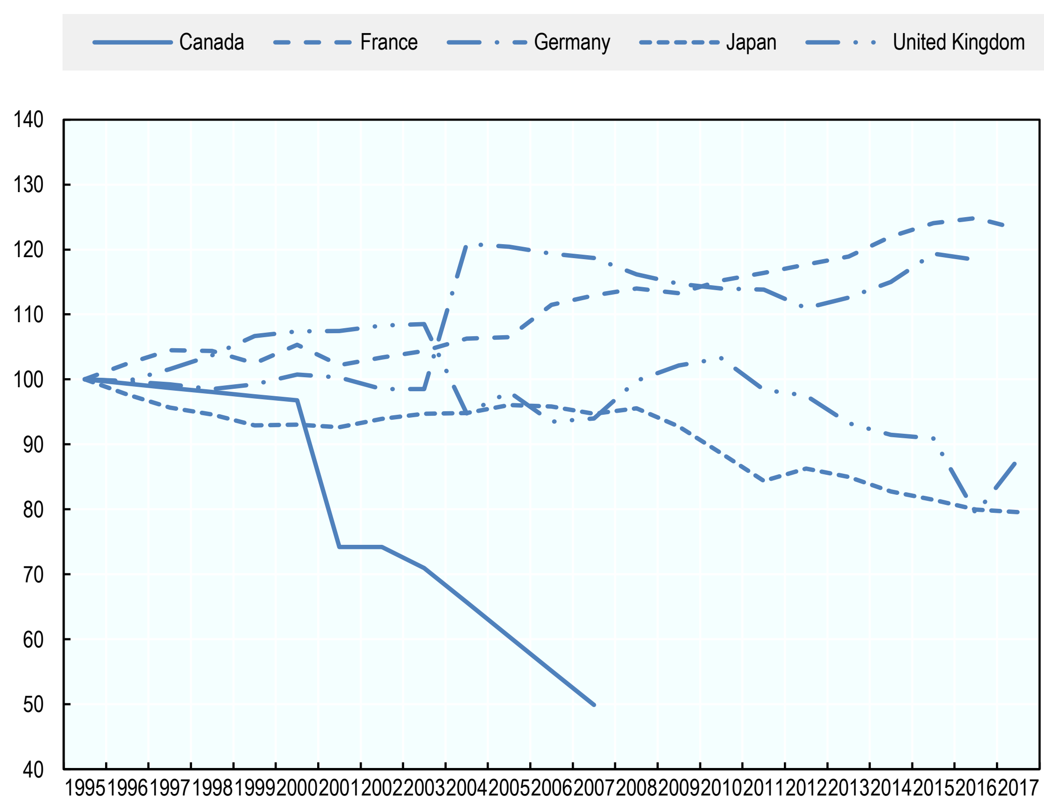
Table 1.3. Urban transport growth by mode

Current demand pathway, compound annual growth rates of passenger-kilometres in percentages

	2015-30	2015-50
OECD urban transport demand		
Private cars	-0.9%	-0.2%
Two and three wheelers	3.0%	2.1%
Bus and BRT	1.7%	1.9%
Rail and metro	2.7%	2.2%
Shared mobility (including all modes)	14.9%	8.4%
Non-OECD urban transport demand		
Private cars	-0.2%	0.4%
Two and three wheelers	3.1%	2.2%
Bus and BRT	3.3%	2.6%
Rail and metro	4.7%	3.6%
Shared mobility (including all modes)	23.8%	12.4%

Figure 1.5. Bus and coach travel in selected countries

Passenger-kilometres, 1995=100



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Car-dominated growth of domestic non-urban transport

Domestic non-urban transport will generate nearly 68 trillion passenger kilometres by 2050, according to projections. This is over three times higher than in 2015. Passenger demand growth will be slightly slower in the long-term compared to the short-term, with a 4.3% compound annual growth through 2030 and a 3.4% rate through 2050 (Table 1.4). Domestic non-urban rail will see the highest compound annual growth rate of all modes (3.8% through 2050). Yet road passenger transport will increase the most in absolute terms, with an increase of 32 trillion passenger-kilometres. This trend is mainly due to strong growth of per capita GDP in developing economies, which will lead to increases in ownership and use of private vehicles in those countries. While domestic non-urban road transport is expected to grow by 29.8 trillion passenger-kilometres in non-OECD countries by 2050, the increase for OEDC countries will be only 2.7 trillion passenger-kilometres.

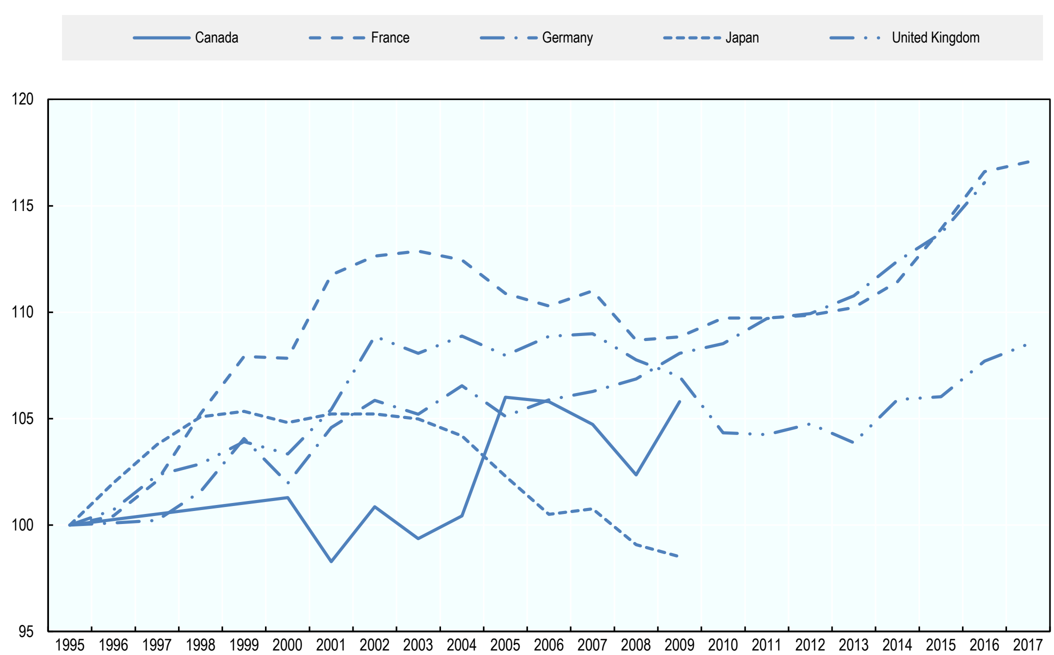
Table 1.4. Growth projections for domestic transport demand by mode, 2015-50

Current demand pathway, global compound annual growth rate in percentages

	2015-2030	2015-2050
Domestic passenger transport demand	4.3	3.4
Domestic non-urban		
Rail	5.5	3.8
Road	4.0	3.4
Aviation	3.6	2.3

Figure 1.6. Travel by private car in selected countries, 1995-2017

Passenger-kilometres,1995=100



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Historic data shows that private car use in many developed economies has increased since the mid-1990s, yet in the long-term further growth will likely be limited. For OECD countries, the compound annual growth rate for non-urban road passenger-kilometres through 2050 is projected to be 1.1%. Some developed economies were already showing little growth or a decline in car use from the early 2000s (Figure 1.6). Then again, countries like France, Germany and the United Kingdom have seen renewed growth in passenger-kilometres. The latest available data shows that total private car use in these countries increased by 17%, 16%, and 9% respectively since 1995.

Current projections of demand pathways see developing economies as the main factor behind the growth in private vehicle passenger-kilometres. The global stock of passenger cars in 2015 is estimated at just over 1 billion vehicles. By 2030, the number is expected to reach nearly 2 billion vehicles, and 3 billion by 2050 (IEA, 2018[23]). China and India alone will have a combined car fleet of over 1 billion vehicles by 2050, according to these estimates. That will be six times greater than in 2015. The overall passenger car fleet in non-OECD countries grows five-fold by 2050 in the current demand pathyway, while the fleet increases by only 16% in OECD countries.

Although fleet size has historically been an important determinant of vehicle-kilometres travelled, this dynamic may change as consumers have better access to alternative forms of mobility. New policies aimed at limiting passenger car use in response to concerns regarding congestion or emissions could affect these trends.

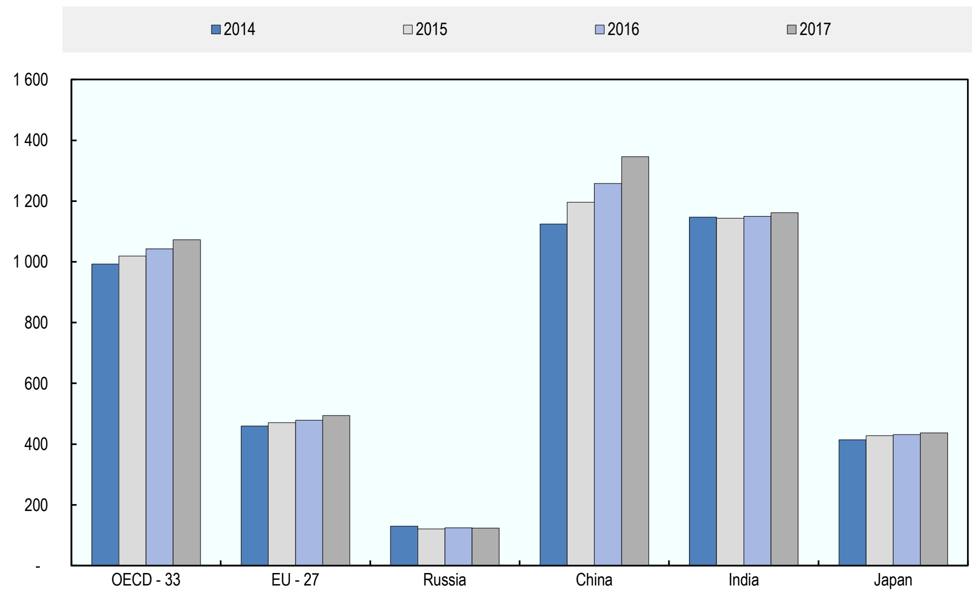
Domestic non-urban rail traffic is predicted to grow by 5.5% annually through 2030, and by 3.8% annually through 2050. The main factor behind this growth are planned rail infrastructure investments in China (Table 1.4). Historical data show strong growth in passenger demand for rail travel in China (Figure 1.7). Global growth of non-urban rail traffic is partly limited by increases in domestic air travel and private car use in developing economies. If shared mobility demand grows significantly, it could also begin to absorb demand for rail travel, particularly due to the cost difference.

High-speed rail can provide a viable alternative to travel by plane or road with regards to cost and efficiency. In particular, many of the developments of high-speed rail within China and Europe have reduced travel demand in aviation for specific routes. Where a new high-speed rail line connects cities that are separated by between 200 and 1 000 kilometres, rail tends to more or less replace aviation (ITF, 2017[19]). Such railway lines are only responsible for a small part of the total domestic inter-urban railway movements, however, and will have a limited impact on total rail traffic.

Nearly all countries have seen growth in rail passenger movements in recent years. China and India each individually generated more rail passenger movements in 2017 than all OECD countries combined (Figure 1.7). China has experienced consistently strong growth in rail passenger traffic, with a total of over 1.3 trillion passenger-kilometres travelled in 2017, which was 7% higher than in 2016. In Japan (1.3%), in OECD countries (2.9%) and in the European Union (3.2%) rail passenger-kilometres continued to grow at a modest pace between 2016 and 2017. On the other hand, rail traffic in Russia fell by 1.2%.

Figure 1.7. Rail passenger traffic in selected countries and regions, 2014-17

Billion passenger- kilometres



Note: Chile and New Zealand are missing from the OECD aggregate. EU does not include Cyprus. 2017 data has been estimated for Australia and Greece.

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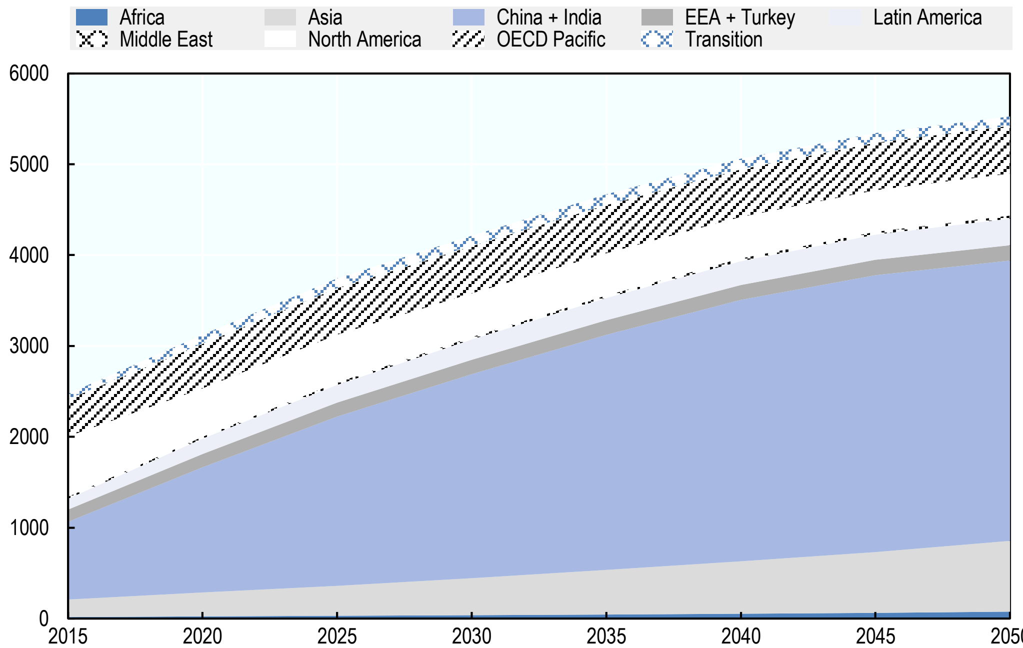
Domestic aviation is expected to experience strong growth through 2030 (3.6% CAGR), driven by increasing demand, especially in China and India (Figure 1.8). By 2050, almost two-thirds of worldwide domestic air passenger-kilometres will come from China, India and the United States. Given the significance of domestic air travel for regional economic development, major markets are likely to encourage its development through fiscal packages and deregulation, as has occurred in the United States (ITF, 2017[19]).

In 2017, more domestic air journeys were undertaken in China than in any other origin-destination market, increasing 14.6% since 2016 to a total of 59 million trips. The fastest growth in domestic aviation occurred in Japan and Korea, where passenger trips increased 26.5% in 2017. India and the United States remain the second and third fastest growing origin-destination markets, growing 17.6% and 4.7%, respectively, in 2017 (IATA, 2018[24]). Passenger-kilometres in Central and South America grew the most (10%), followed by Asia and Oceania at 9.6%, and Europe at 8.1% (ICAO, 2018[25]).

Figure 1.8. Projected domestic air transport demand by region, 2015-50

Current demand pathway by region of origin, billion passenger-kilometres



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Fast-growing international passenger aviation

Global demand for air travel will continue to increase through 2050, according to the current demand pathway. The main drivers are economic growth in developing economies and improving air connectivity. The projected growth rate for global air passenger-kilometres is 4.5% through 2030 and 3.3% through 2050. Demand for domestic and international air transport combined will rise from 7 trillion passenger-kilometres in 2015 to 22 trillion in 2050 (Figure 1.9). The further rise of low-cost carriers will make air travel less expensive than many trips previously using other modes. However, the future growth of air passenger transport will depend on whether the network is able to keep up with the demand. Given the uncertainty of how air networks will evolve there are notable differences between the projections of the current demand pathway and alternative scenarios (see Chapter 4).

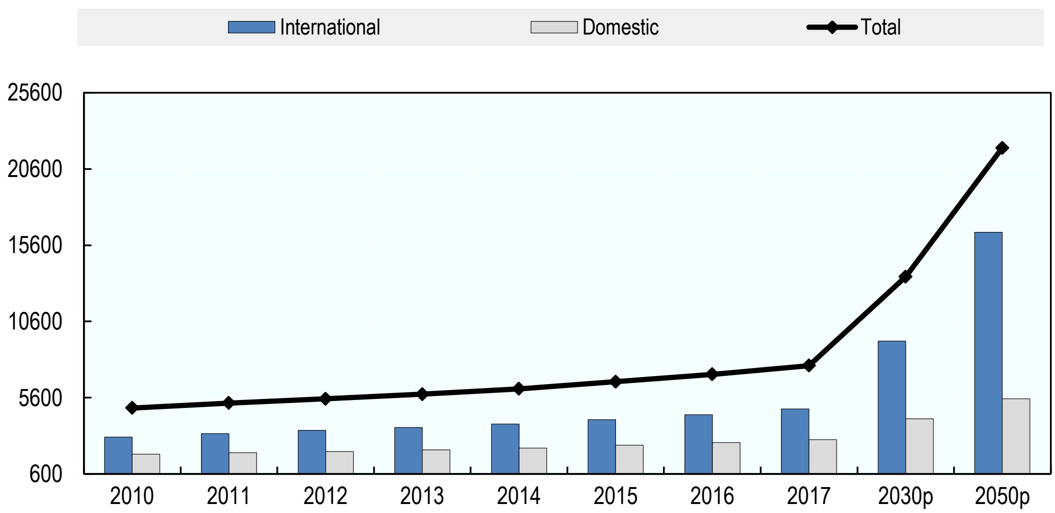
International air passenger traffic reached a record level in 2017 with 4.9 trillion passenger-kilometres, an increasing of more than 8% on 2016 (Figure 1.9). Since 2010, international flights, measured in passenger-kilometres, have increased by 61%. More than 4 billion passengers (+7.1%) travelled by plane in 2017. On average, a person flew once every 22 months, twice as frequently as in the year 2000 (IATA, 2018[26]); (ICAO, 2018[25]). Asia and the Pacific region were responsible for 34% of global air passenger-kilometres in 2017, followed by Europe with 27% and North America with 23% (IATA, 2018[27]). Projections see the number of flights and air passengers double in the next 15 years (ICAO, 2018[25]).

International passenger air travel will see its strongest growth primarily in developing economies. It will be particularly strong in Asia; international air passenger-kilometres in

China and India alone are expected to increase more than three-fold by 2030 and almost seven-fold by 2050. At that point these two countries' alone will be responsible for a quarter of worldwide air traffic (Figure 1.10). In Africa, demand for air travel is currently growing faster than capacity which in 2017 rose by 6.7% on the previous year. By 2050, demand is expected to be over nine times the current levels at 1.3 trillion passenger-kilometres.

Figure 1.9. World air passenger traffic, 2010-50

International and domestic, billion passenger-kilometres



Source: ICAO (2018[28]), Annual Report of the Council 2017 for data through 2017. Data for 2030 and 2050 are ITF projections from the current demand pathway using region of origin.

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The number of city pairs with regular air services between them reached a record high of 20 000 in 2017. In 2016, there had been 1 300 fewer pairs. Better air connectivity has helped to lower costs for travellers and shippers alike. It partly explains the boom in air passenger movements between 2014 to 2017 (IATA, 2018[26]). The number of city pairs in the global air network will grow by 2.8% annually through 2050, based on a projection of the current demand pathway. Jet fuel prices increased by 25% in 2017 relative to 2016 but are still much lower than in the previous decade. This has helped airlines' profit margins to remain quite stable (ICAO, 2018[25]). The expansion of tourism also adds to growing demand for air travel. Tourists spent 6% more on air travel in 2017 compared to 2016, amounting to an estimated total of USD 711 billion (IATA, 2018[26]).

The ranking of he world's busiest airports has remained more or less stable. Atlanta's Hartsfield-Jackson International Airport in the United States remains the busiest airport in the world, transporting almost 104 million passengers in 2017 - a slight drop (-0.30%) from 2016. Of the ten highest-volume aviation hubs in 2015, only Dallas-Fort Worth Airport in the United States did not make the 2016 top ten. It was replaced by Shanghai's Pudong Airport in China (which also surpassed the Charles de Gaulle Airport in France) with a passenger volume of 66 million in 2016, nearly three times higher than a decade earlier.

Figure 1.10. Projected international air transport demand by world region, 2015-50

Current demand pathway by region of origin, billion passenger-kilometres

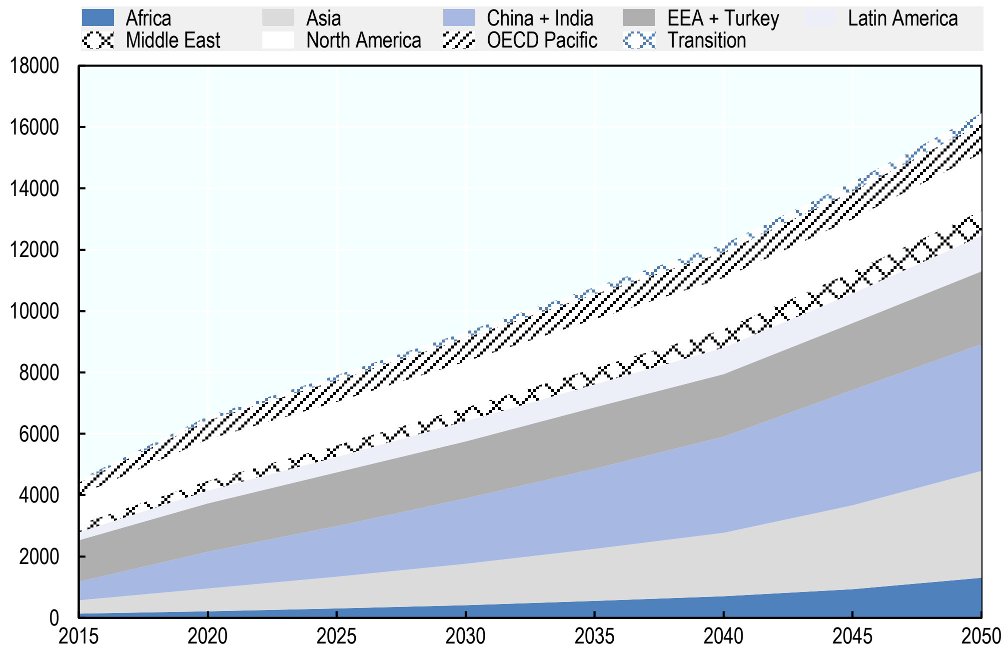

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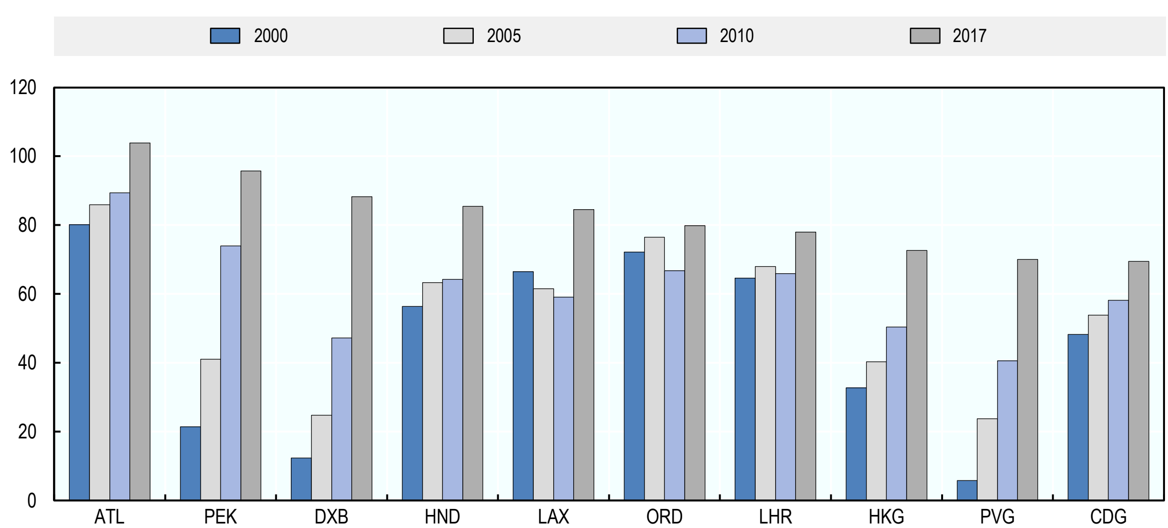
Figure 1.11. Top ten busiest airports in 2017

Million passengers



Note: Airports, from left to right: Atlanta Hartsfield-Jackson, Beijing Capital, Dubai, Tokyo Haneda, Los Angeles, Chicago O'Hare, London Heathrow, Hong-Kong, Shanghai Pudong, Paris Charles de Gaulle
Source: ACI (2019[29])

StatLink http://dx.doi.org/10.1787/888933972164

Freight transport growth faces uncertainties

Global freight demand will triple between 2015 and 2050, based on the current demand pathway. Of the 108 trillion t-km transported worldwide in 2015, 70% travelled by sea, 18% by road, 9% by rail and 2% by inland waterway. Less than 0.25% of global freight in t-km is transported by air (Figure 1.12). The projected compound annual growth rate of freight through 2030 is 3.1%. Due mainly to downward adjustments in the projections for trade and economic growth, this is a slightly lower figure than in the 2017 edition of the *Transport Outlook* projections (Table 1.5). Freight demand will grow faster over the longer term, at 3.4% through 2050.

Air freight, while representing a marginal share of total freight transport, will have the highest compound annual growth rate of all modes through 2030 (5.5%) and 2050 (4.5%). Its growth is driven by larger shares of high-value goods being transported by air, most notably in China. Maritime shipping will remain the largest contributor to global tonne-kilometres. Ships will carry out more than three-quarters of all goods movements by 2050 (Figure 1.12). The remaining goods will be transported by road (17%) and rail (7%).

Freight demand depends primarily on economic growth and international trade activity. In light of the current instability of the global economy and the rising tensions over trade, the accuracy of growth projections for freight transport in the current demand pathway is uncertain. Projected figures could shift as a result of increased protectionism or a global economic downturn, but also de to improvements in freight transport capacity in countries or regions with significant growth potential. In Asia, for instance, capacity will need to increase to accommodate future freight transport demand.

Figure 1.12. Projected freight transport demand by mode

Current demand pathway, billion tonne-kilometres

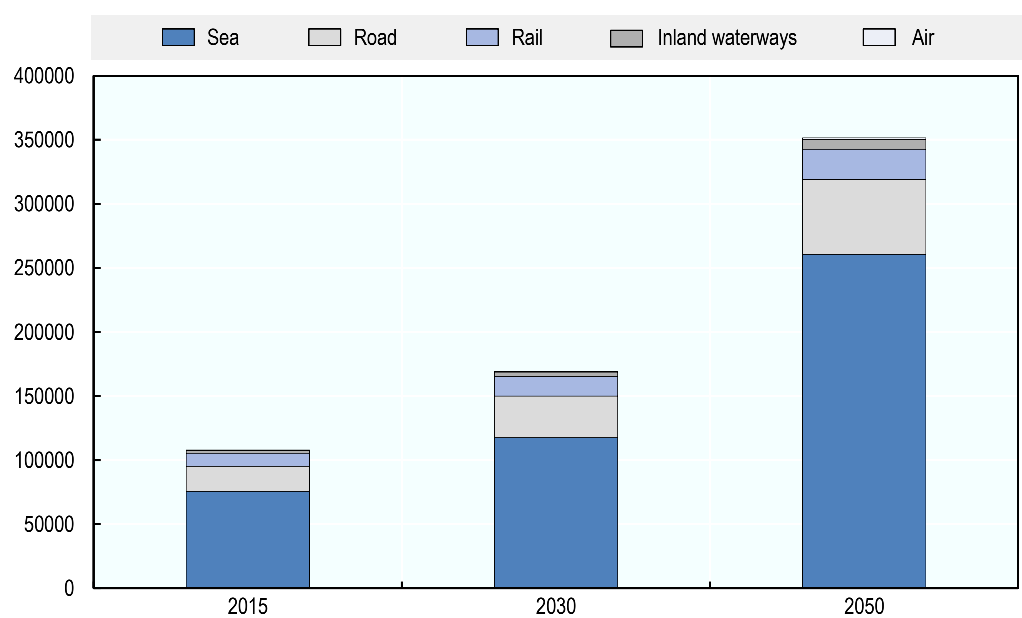


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Table 1.5. Projected growth rates of freight transport demand

Current demand pathway, global compound annual growth rate in percentages

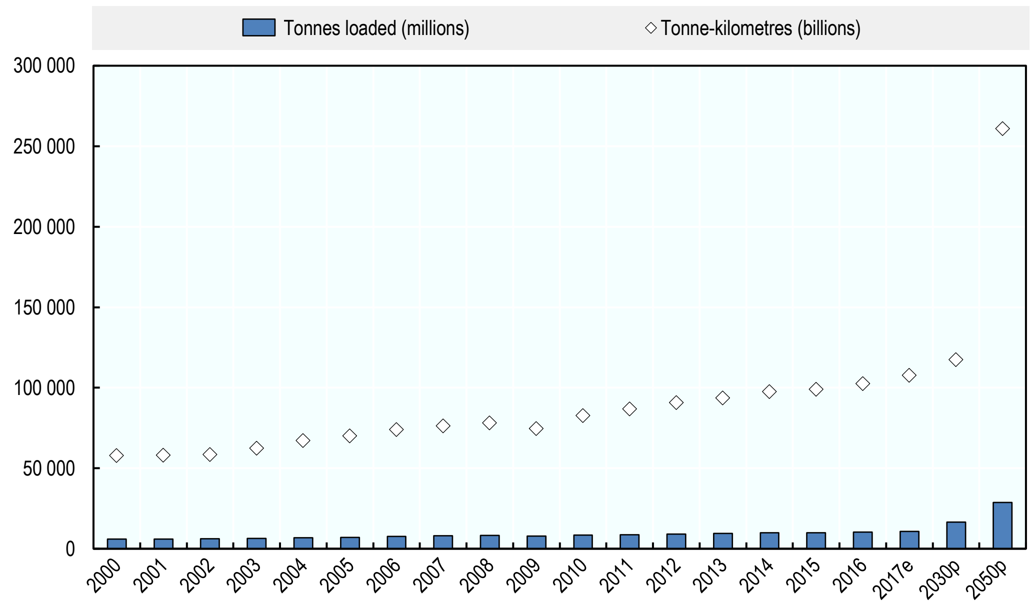
	2015-2030	2015-2050
Freight transport demand	3.1	3.4
Rail	2.7	2.5
Road	3.5	3.2
Inland waterways	3.4	3.8
Aviation	5.5	4.5
Sea	3.0	3.6

Maritime ships carry most of global freight

Maritime shipping covers most of the movement of goods over long distances. This will continue to be the case in the coming years. The current demand pathway projects that maritime freight transport will grow at a compound annual growth rate of 3.6% through 2050 (Table 1.5). This will lead to a near tripling of maritime trade volumes by 2050.

The economic value of freight flows in the North Pacific and Indian Oceans will increase nearly four-fold between 2015 and 2050. Approximately one third of all maritime freight movements in 2050 will take place in these two regions (Figure 1.14). The North Atlantic Ocean will remain the third-busiest maritime corridor, with 15% of maritime freight movements in 2050, equalling 38 trillion tonne-kilometres. A recent trend, particularly strong in China, is the relocation of factories inland. This may impact mode choice for Eurasian freight flows if these relocations significantly increase the time and cost of maritime shipments relative to inland modes. Seaborne trade volumes grew 4% in 2017, the fastest rate since 2012, An estimated 10.7 billion tonnes were transported by sea that year. In terms of tonne-kilometres, global shipping activity amounted to over 58 trillion in 2017, an in crease of 5% on 2016. An estimated 752 million twenty-foot equivalent units (TEUs) were shipped through container ports. The size of the global ship fleet also grew +3.3% in 2017, but the growth in capacity was surpassed by increased freight volumes. UNCTAD projects that maritime freight volumes will continue expand through 2023, although this could change depending on the development of international trade agreements (UNCTAD, 2018[30])

Figure 1.13. Total maritime trade demand, 2000-50



Note: Data for 2017 are estimates; data for 2030 and 2050 are projections.
Source: Data for 2000-17 are from UNCTAD (2018[30]) Review of Maritime Transport (tonnes loaded) and Clarksons Research (tonne-kilometres), as cited in UNCTAD (2018[30]).

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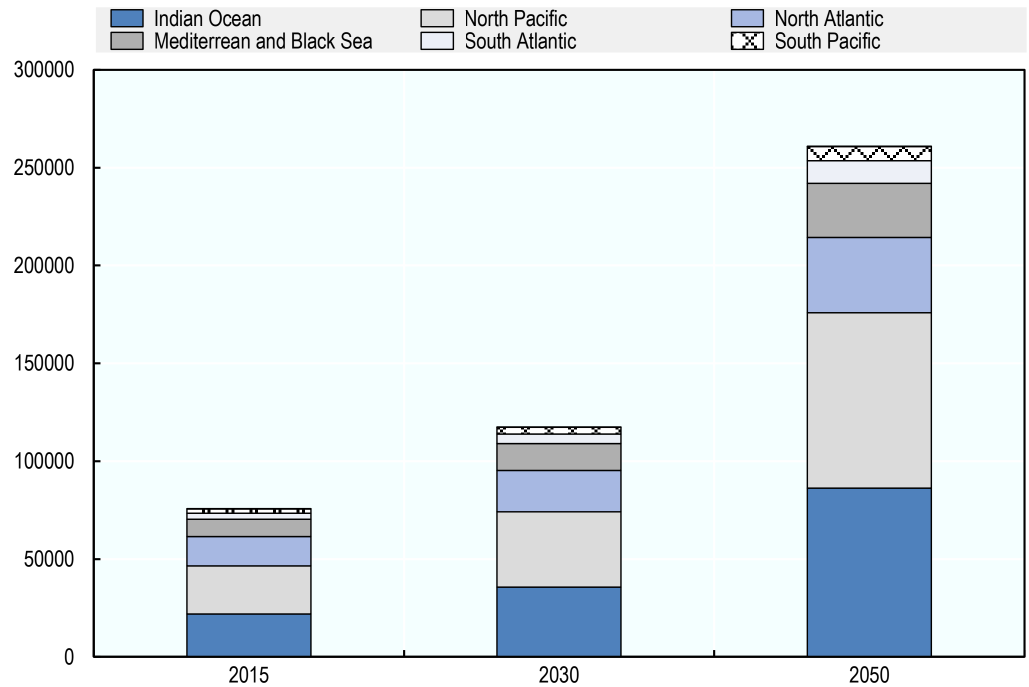
Fuel transport patterns have been shifting as demand for cleaner energy sources such as natural gas is rising, especially in Asia. Growth in crude oil shipments has slowed. In 2016, crude oil shipments grew by 2.4%, down from 4% in 2017 (UNCTAD, 2018[30]). Containerised trade increased globally in 2017 (+6.4%), most notably because of increased shipments from the Atlantic basin to Asia (UNCTAD, 2018[30]). Small island nations have experienced a particularly steep rise in maritime freight costs since 2013. The growth rate of costs in these developing economies is just above the average growth rate in developing economies (UNCTAD, 2017[31]).

The future of the maritime freight sector depends in particular on international trade agreements, the development of transcontinental inland routes, and changes in global energy use. The Economic Partnership Agreement between the European Union (EU) and Japan as well as the Comprehensive Economic and Trade Agreement (CETA) between the EU and Canada will likely lead to further increases in trade volumes. Changing global value chains in rapidly developing economies such as China and India will also determine how freight flows evolve. Growing global e-commerce will also likely contribute to long-term growth in demand for container shipping. Evolutions in the energy sector and a global transition toward cleaner energy will also shape the future of the maritime industry (UNCTAD, 2018[30]).

Figure 1.14. Maritime trade demand projections by region, 2015-50

Current demand pathway, billion tonne-kilometres



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Anticipating bottlenecks and planning necessary land acquisitions for new port capacity and connecting inland corridors will be crucial for accommodating growing maritime freight transport. This presents a formidable challenge, however: Projections for trade trends and mode distributions are beset with uncertainties ,while maritime infrastructure investments are costly and have a long lead time. The risk of over-investment in capacity expansion if expected growth in trade flows does not materialise is thus not negligble.

Slower-than-expected growth in international trade has led to overcapacity in certain maritime transport sectors and locations. Since capital investments in the shipping industry cannot be easily recuperated, companies may seek to cut costs in other ways in order to maintain profitability. This could lead to shipping operators concentrating on a limited number of ports and routes, which in turn could strain the capacity of these ports. Current demand pathway projections indicate that scheduled investments in port capacity should be capable of accommodating maritime freight demand through 2030 in most areas of the world except in South Asia.

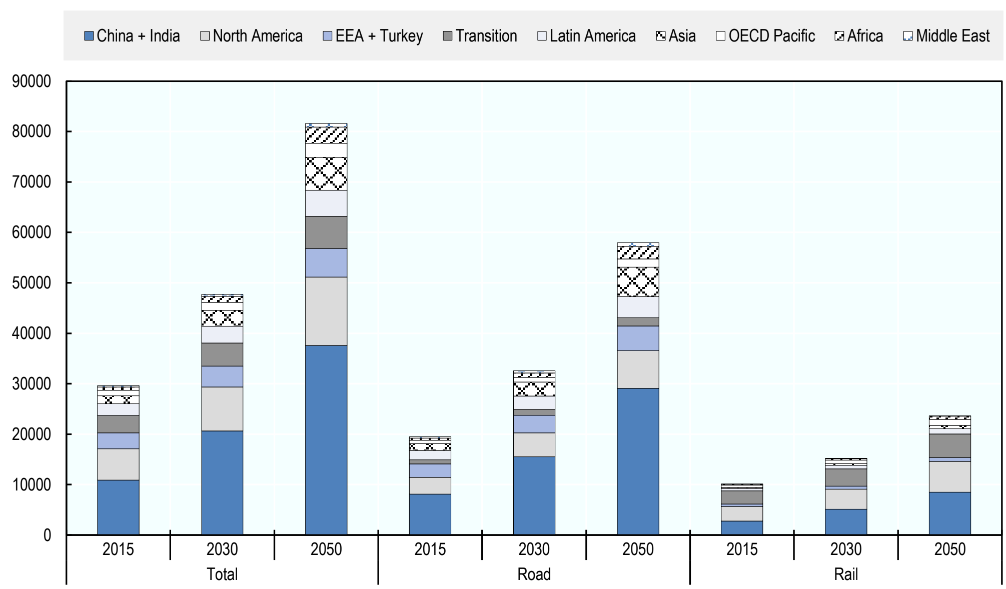
Surface freight demand growth strong in Asia

Global surface freight movements, i.e. transport via road, rail and inland waterways are projected to grow 175% between 2015 and 2050. They will carry 82 trillion t-km or 24% of total freight demand (Figure 1.15). Surface freight flows in China and India taken together made up 37% of total surface freight flows in 2015. By 2050, Asia (including China and India) will be responsible for over 54% of global surface freight demand. Africa will see the fastest grwoth in road and rail tonne-kilometres, with an increase of+393%vy 2050 on 2015, followed by the Asian continent with an increase of +254%.

Growth will be lee pronounced in the Middle East (165%), the OECD Pacific countries (+154%), North America (+119%) and Latin America (+119%), In transition economies[1] (+83%), and Europe (+82%) it will be significantly lower. Among the surface modes, road freight will increase exponentially in Africa (+435%) and the Asian continent (+269%) over this period.

Figure 1.15. Projected demand for surface freight transport by region

Current demand pathway, billion tonne-kilometres



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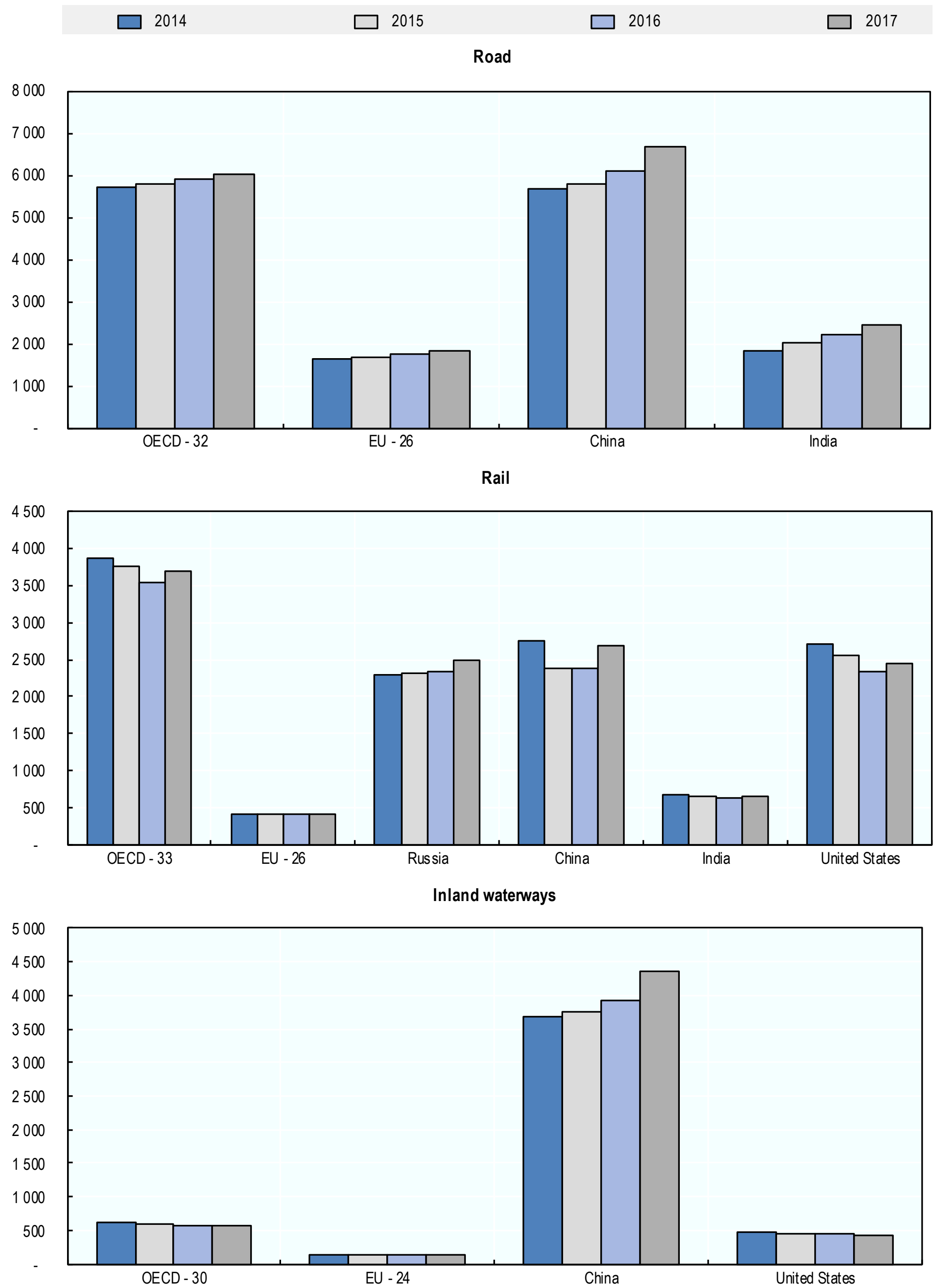
Over the past few years, road freight traffic levels have been growing across the globe, albeit at a more modest rate in the European Union (Figure 1.16). Surface freight volumes showed signs of recovery from the global economic downturn as early as 2011, but this trend is not uniform across modes and regions. China and India saw the fastest growth in road tonne-kilometres since 2016, with increases of 9.3% and 9.4% in 2017 respectively. China alone transported 6.7 trillion tonne-kilometres of road freight in 2017, nearly 700 billion tonne-kilometres more than the total freight traffic of OECD countries.

Global rail freight volumes have declined in recent years, but for many countries 2017 marked a slight reversal in this trend. Rail tonne-kilometres in China grew by 13.3% on the previous year, returning nearly to their 2014 level. Russia also saw a notable increase of 6.4% in rail tonne-kilometres in 2017. Rail freight in India (+5.5%) and the United States (+5.2%) also grew significantly. Recent declines in rail traffic (Figure 1.16) are not likely to represent a strong long-term modal switch between road and rail, due to the fact that the compound annual growth rates of road and rail freight demand through 2050 are projected to be similar (Table 1.5).

Inland waterway freight traffic in China is projected to remain well above that of any other country or even any other continent, with strong growth rates through 2017. The volume of inland waterway freight in China was estimated at 4.4 trillion tonne-kilometres in 2017, a 10.9% increase from 2016.

Figure 1.16. Surface freight traffic by transport mode, 2014-17

Billion tonne-kilometres



Note: Add the note here. If you do not need a note, please delete this line Aggregates for road do not include Chile, Cyprus, Israel or Malta. Rail aggregates do not include Belgium, Chile or Cyprus. Inland waterway aggregates do not include Canada, Chile, Greece, Portugal and Sweden. Data for 2017 was estimated for the following countries: the United States for inland waterways, Australia and Greece for rail, Australia, Canada, Iceland, Italy, South Korea, and the United States for road.

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Growth in surface freight volumes has slowed in recent decades. Planned large-scale infrastructure investments and legislation facilitating greater connectivity and integration could slightly shift this trend, however.The European Union will provide a total of EUR 30.6 billion between 2021 and 2027 via the Connecting Europe Facility to improve interoperability and border crossing procedures in Europe (Van Leijen, 2018[32]). There have also been some advances in the European Commission's proposal to increase road charges and coverage so as to be more on par with those of railways (Van Leijen, 2018[33]).

Several initiatives aim to better connect China's economy to markets in Europe, Africa and Asia and are likely to shift freight patterns. A new railway line launched in 2018 now connects the freight hub of Chengdu, the capital of Sechuan, with Vienna in Austria (Van Leijen, 2018[34]). A recently established railway route links China, Kazakhstan, Azerbaijan, Georgia and Turkey (Van Leijen, 2018[35]). China also announced plans in June 2018 to build a railway line between Tibet and Nepal, an initiative endorsed by the Nepali Prime Minister (The Straits Times, 2018[36]).

Technological advances and innovtions in logistics could influence the current demand pathway projections for freight flows. Enforcement of road freight regulations will become with the increased availability of extensive freight transport data. This will improve governments' ability to monitor the effectiveness of their road freight policies and presents opportunities for data-driven regulation and enforcement (ITF, 2017[37]). The use of autonomous trucks could also impact the cost and efficiency of road freight transport. Chaoter 5 offers a detailed analysis of these potential developments.

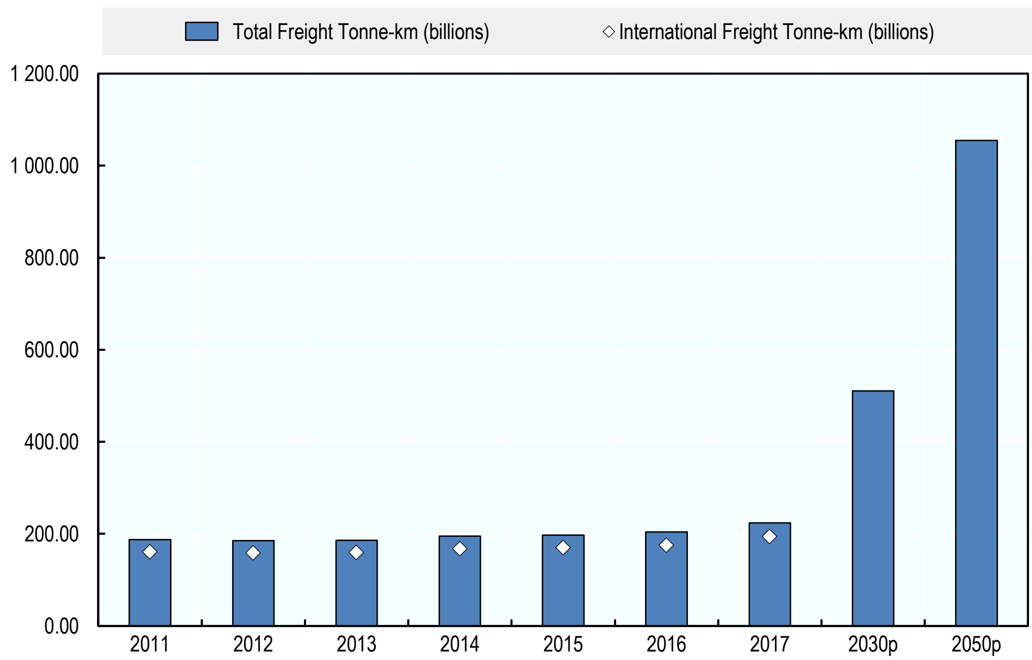
Aviation outpaces growth of other freight modes

Air freight generated 9.5% more tonne-kilometres in 2017 than in 2016, a more than double the growth rate of the previous year. International air freight flows grew even faster with a grwoth rate of 10.4%. Africa had the highest growth rate (+25.2%), although from a low level as Africa also had the smallest amount of traffic (4 billion t-km) of all regions in 2017. In terms of regional shares, Asia and the Pacific were responsible for nearly 40% of global air freight traffic, followed by Europe with 23%, North America at 20% and a share of 14% for the Middle East (ICAO, 2018[28]).

By 2030, planes will transport 500 billion tonne-kilometres of goods, according to the current demand pathway projection. By 2050, the total volume of air freight could exceed 1 trillion tonne-kilometres (Figure 1.17). Global air freight demand is expected to grow at faster rates than any other mode, with a compound annual rate of 5.5% through 2030 and 4.5% through 2050 (Table 1.5) still, aviation will only account less than 0.25% of global freight movements in 2050 in t-km (Figure 1.12). Yet it is an integral part of global supply chains, as the only mode suitable for transporting certain perishable or time-sensitive goods. This is reflected in the high share of air freight when measured in value terms 35% of the value of global trade, equalling USD 5.6 trillion worth of goods were moved by planes in 2017 (IATA, 2018[26]). Thus, comparatively small air freight flows can have considerable economic significance.

Figure 1.17. World air freight traffic, 2011-50

Billion tonne-kilometres



Note: Data for 2030 and 2050 are ITF predictions from the current demand pathway.
Source: ICAO (2018[28]), Annual Report of the Council 2017 for data 2011 to 2017.

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One reason behind high recent growth in air freight volumes is the global inventory re-stocking cycle, during which unexpected spikes in demand require rapid restocking of inventory. However, evidence suggests that this cycle is ending (IATA, 2018[38]). Despite an easing of growth, demand for air freight continues to experience strong growth overall, which has put significant strain current air freight transport capacity (IATA, 2018[24]). However, recent rises in protectionist trade policies appear to be softening this demand. Most notably, the growth rate for manufactured goods exports has been slowing in late 2018 in China, Germany and the United States (IATA, 2018[38]).

Aviation has become central to e-commerce. Nearly 90% of business-to-consumer e-commerce goods were transported by air in 2017, a steep increase from the 16% of e-commerce goods transported by air in 2010 (IATA, 2018[24]). The aviation industry has also been working to digitalise supply chains (e-freight) for the past decade to improve efficiency. Electronic air waybills (e-AWB) were used for 50% of air freight in 2017. However, methods and procedures for the e-AWB are not yet harmonised throughout the world, with some countries constrained by regulations that do not allow digital data to be shared (IATA, 2018[26]).

Aviation infrastructure is not developing at the pace needed to respond to growing demand for air freight. This could pose a critical problem in the future since infrastructure expansion requires long-term planning and air freight demand is predicted to grow very fast, reaching 4.7 times the 2017 level by 2050.

Notes

[1] Transition economies include former Soviet Union countries and non-EU south-eastern European countries.

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Chapter 2. Impact of transport policies on CO_2 emissions to 2050

This chapter provides projections of future transport CO_2 emission based on a current ambition scenario and a high ambition scenario. The high ambition scenario reflects the extent to which known transport decarbonisation measures could mitigate the sector's CO_2 emissions. The simulations show that emissions reductions will fall short of climate objectives set out in the Paris Agreement in 2015 even in the high ambition scenario. Achieving these objectives will hinge on scaling up known strategies as well as bringing to bear innovative measures that will enable transport demand to be satisfied with minimal CO_2 emissions.

The challenge of decarbonising transport

Decoupling transport activity from CO_2 emissions will be critical for achieving climate objectives while maintaining the mobility of passengers and freight flows. How increases in transport demand will be satisfied in the coming years will be shaped by transport policies. The signing of the Paris Agreement in 2015 signalled a global consensus on the magnitude of the risks posed by climate change and the importance of coordinated efforts to address them. In that same year, the United Nations General Assembly adopted seventeen Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development. Seven of the SDGs are linked to sustainable transport (Table 2.1).

Table 2.1. Transport-related targets in the United Nations Sustainable Development Goals

Goal	Target
Sustainable Development Goal (SDG) 2 Zero hunger	Target 2.3 Double the agricultural productivity and income of small scale food producers (access to markets)
SDG 3 Good health and well-being	Target 3.6 Halve number of global deaths and road injuries from traffic accidents Target 3.9 Reduce deaths and illnesses from pollution
SDG 7 Affordable and clean energy	Target 7.3 Double the global rate of improvement in energy efficiency
SDG 9 Industry, innovation and infrastructure	Target 9.1 Develop sustainable and resilient infrastructure
SDG 11 Sustainable cities and communities	Target 11.2 Provide access to safe, affordable, accessible and sustainable transport systems for all Target 11.6 Reduce the adverse environmental impact of cities
SDG 12 Responsible consumption and production	Target 12.c Rationalise inefficient fossil-fuel subsidies
SDG 13 Climate action	Target 13.1 Strengthen resilience Target 13.2 Integrate climate change measures into national plans

Source: Secretary-General's High-level Advisory Group on Sustainable Transport (2014[1]) , Mobilizing Sustainable Transport for Development.

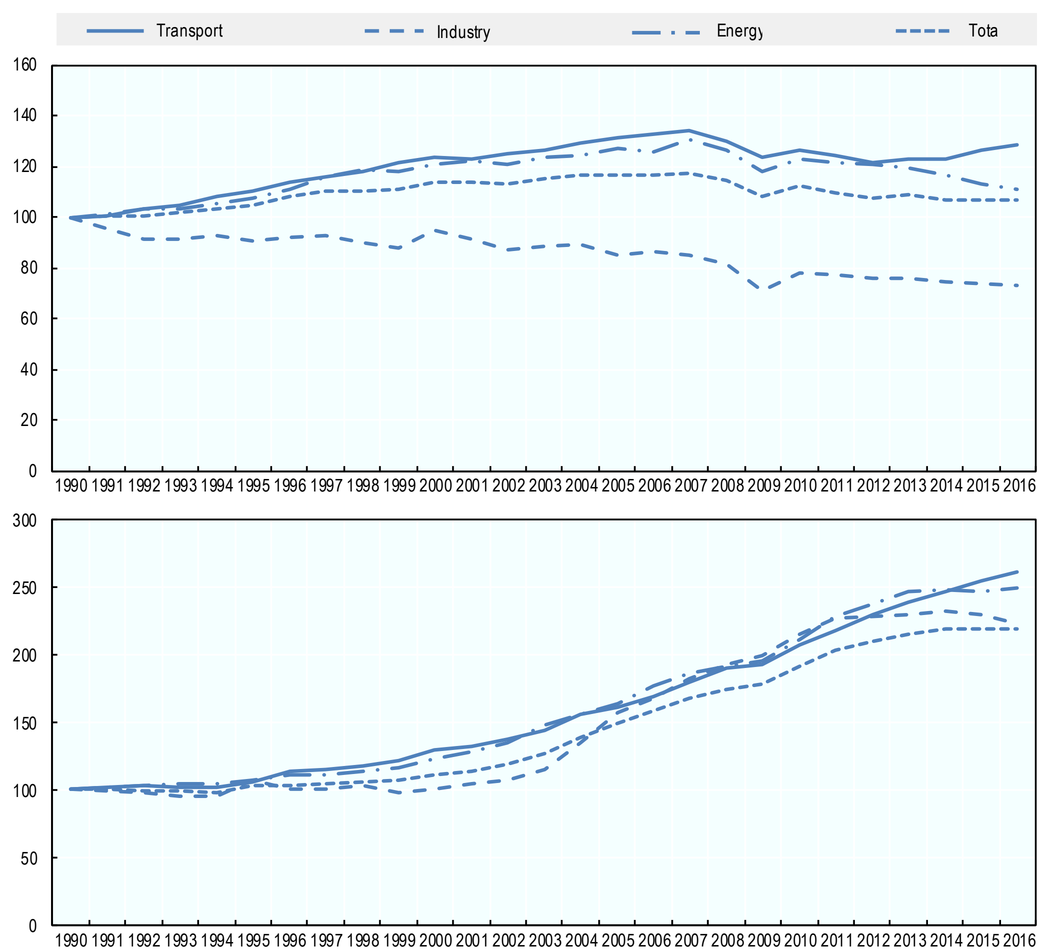
An evaluation of the Nationally Determined Contributions (NDCs) submitted in the context of the Paris Agreement reveal, however, that stated ambitions will fall short of maintaining the average global temperature at "well-below 2 degrees Celsius" above pre-industrial levels (ITF, 2018[2]; PPMC-SLoCaT, 2016[3]; UNFCCC, 2016[4]). Although most NDCs mention the importance of decarbonising transport, only one in ten define a specific emissions reduction target for the transport sector (ITF, 2018[2]). The 24th meeting of the Conference of the Parties to the United Nations Framework on Climate Change (COP24) in December 2018 worked to identify concrete actions that Parties can undertake in order to mitigate CO_2 emissions. While the roadmap produced provides standards for emissions accounting, existing NDCs were not revised. As a result, the emissions targets set therein remain insufficient. The lack of specific and actionable transport-related mitigation measures evident in the NDCs constitutes a major source of uncertainty with respect to achieving climate objectives, given that emissions from transport amounted to one quarter of the total energy-related CO_2 emissions in 2016 (IEA, 2018[5]).

Decarbonising transport will require unprecedented efforts and coordination. The sector is highly reliant on fossil fuels, which provide over 92% of its energy use (IEA, 2017[6]). Oil continues to be the biggest contributor to emissions in OECD countries, generating 4.1 billion tonnes of CO_2 in 2016 and 41% of total CO_2 emissions. Final energy use in

OECD countries rose by 35 million tonnes of oil equivalent (Mtoe). This includes an increase of 19 Mtoe of energy use in the transport sector, a trend that is apparent across all regions (IEA, 2018[5]). In 2016, transport accounted for 30% of CO_2 emissions in OECD countries and 16% of all CO_2 emissions in non-OECD countries. Unlike in other sectors, emissions from transport have continued to increase in recent years in both OECD and non-OECD countries, in spite of concurrent technological advances and the implementation of mitigation measures (IEA, 2018[5]).

Figure 2.1. CO_2 emissions by sector

OECD economies (top) and non-OECD economies (bottom), 1990=100



Source: IEA (2019[7])

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Formidable challenges will need to be overcome to prevent this increase. The carbon intensity of fuels and the energy intensity of technologies will need to be reduced, the share of travel undertaken by emissions-intensive modes shifted, and overall travel demand curtailed. The pace of these shifts will be hampered by rapid growth of transport demand as well as institutional and behavioural inertia. The political feasibility of transport policy measures such as fuel taxes is already constrained by societal developments such as rising inequality (ITF, 2018[8]). Strong shifts in user preferences could also alter the trajectory of mode choices, and thus the uptake of new technologies and services, in the coming years. Changing social norms could contribute to driving shifts in transport and mobility paradigms, even though these are ultimately unpredictable (Nyborg et al., 2016[9]).

Political ambition is critical for mitigating transport CO_2 emissions

Urgent action by national governments is needed to follow through on the mitigation commitments made in their respective NDCs. The Intergovernmental Panel on Climate Change (IPCC) estimated that transport-related CO_2 emissions could double by 2050 and triple by 2100 if no new policies were put in place (IPCC, 2014[10]). In this scenario, global average temperature rises by more than four degrees Celsius above pre-industrial levels (IPCC, 2014[11]). More recent analysis identifies both the urgency of political action to reduce CO_2 emissions and the important role of the transport sector in this ultimate goal (IPCC, 2018[12]). According to estimates from the International Energy Agency (IEA) total emissions from transport must fall to approximately 3 000 million tonnes per year by 2050 in order to limit average global temperature increase to well-below 2ºC above pre-industrial levels (IEA, 2017[6]).

The ITF modelling results below present CO_2 emissions projections to 2050 under a current ambition scenario and a high ambition scenario; with a view to help assess the importance of concerted mitigation efforts in reaching the objective of the Paris Agreement.

The current ambition scenario assumes that current policies will remain in place and that countries will follow through on the mitigation commitments made as of late 2018. The current policies and mitigation measures considered include pricing disincentives for private car use, restrictions on car use in some city centres, land-use measures that increase urban density, public transit supply and integration, and a moderate increase in carbon pricing by 2050. The technological assumptions of the current ambition scenario, such as electric vehicle (EV) penetration and fuel efficiency improvements, are broadly in line with the new policies scenario (NPS) of the mobility model developed by the IEA (IEA, 2018[13]).

Under the high ambition scenario, the above measures are implemented to a greater extent. Pecuniary and regulatory measures targeting car use are intensified, as are land-use policies that result in varying degrees of densification in city centres around the world. More stringent carbon pricing is also implemented. The high ambition scenario further assumes technological advances such as the rapid electrification of transport and decarbonisation of the power sector, in line with the IEA's EV30@30 scenario (IEA, 2018[5]). Underlying assumptions regarding exogenous determinants of transport demand, such as GDP, population, and trade remain the same as in the current ambition scenario. Assumptions regarding policies and potential disruptive developments to the transport sector for the two scenarios are reviewed in Table 2.2. More detailed information on these assumptions is provided in Chapters 3, 4 and 5.

Table 2.2. Overview of the International Transport Forum current ambition and high ambition scenarios

Assumption	Sector	Current ambition	High ambition
Mitigation measures			
Car access restrictions	Urban passenger	By 2050, 20% of car trips are affected by constraints (e.g. low emission zones)	By 2050, 40% of car trips are affected by constraints
Parking Pricing	Urban passenger	0%-20% higher than the expected purchase power of travellers by 2050, depending on the region	10%-40% higher than the expected purchase power of travellers by 2050, depending on the region
Public transit integration and expansion	Urban passenger	Past trends continue to 2050	Past European trends continue to 2050 for all world regions
Mobility as a Service	Urban passenger	By 2050, 20% of travellers use MaaS solutions to plan their journeys	By 2050, 50% of travellers use MaaS solutions to plan their journeys
Land-use policies to increase urban density	Urban passenger	Depending on the region, either stable or slight urban sprawl by 2050	Depending on the region, urban densification of 5-10% by 2050
Carbon pricing	Non-urban passenger	Modest increase by 2050	Substantial increase by 2050
International coal and oil consumption	Freight	Moderate reductions (following OECD ENV-Linkages model, (Château, Dellink and Lanzi, 2014[14])	Accelerated reductions
Logistics efficiency	Freight	Moderate efficiency improvements following the IEA NPS (IEA, 2018[13])	Moderate efficiency improvements following the IEA NPS (IEA, 2018[13])
Efficiency improvements and electric vehicles	Urban passenger, Non-urban passenger, Freight	Moderate efficiency improvements and electric vehicle uptake following the IEA NPS (IEA, 2018[13])	Substantial efficiency improvements and widespread electric vehicle uptake following the IEA EV30@30 scenario (IEA, 2018[5]) For freight, same as the current ambition scenario
Potentially disruptive developments			
Assumption	**Sector**	**Current ambition**	**High ambition**
Autonomous vehicles	Urban passenger, Non-urban passenger, Freight	Continuation of current levels of uptake	

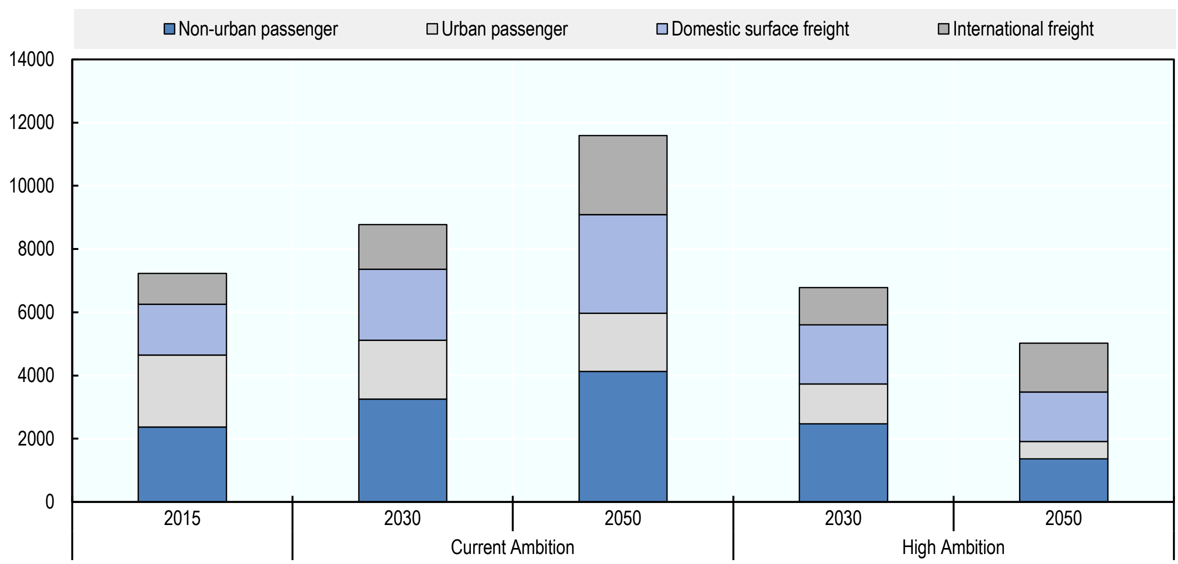
Shared mobility	Urban passenger, Non-urban passenger	Continuation of current levels of uptake	Continuation of current levels of uptake for urban passenger; increased uptake for non-urban passenger
Teleworking	Urban Passenger	2-20% of trips are affected by 2050, depending on the region	3-25% of trips are affected by 2050, depending on the region
Long-haul low-cost air carriers	Non-urban passenger	Continuation of current levels of uptake	
Energy innovations in aviation	Non-urban passenger	Alternative fuels are four times more expensive relative to conventional fuels. Range of electric planes reaches 1 000 km by 2050	Alternative fuels are three times more expensive relative to conventional fuels. Range of electric planes reaches 1 600 km by 2050
Ultra-high-speed rail	Non-urban passenger	Continued development of conventional high-speed projects that are already underway as well as where economically feasible	
E-commerce	Freight	Slight increase in urban freight demand (5% in more developed regions by 2050)	
3D printing	Freight	No change from current uptake	
New international trade routes	Freight	Planned infrastructure capacity and connectivity improvements	
Energy transition for long distance heavy freight	Freight	Continuation of current fuel composition and technologies	
High capacity vehicles	Freight	5% increase in the uptake of HCVs for inter-urban road freight. HCV use characterised by a 50% increase in truck loads and a 20% decrease in costs per tonne-kilometre	

The simulations indicate that current transport policies will fail to mitigate increases in transport CO_2 emissions in the face of strong growth in transport demand over the coming years (Figure 2.2). The ITF modelling framework estimates that emissions in 2015 amounted to 7 230 mega tonnes (Mt)[1]. The modelling results suggest that OECD countries were responsible for half of all transport-related CO_2 emissions in 2015, excluding international aviation and marine transport activity, although they comprised only 17% of the world's population that year. Under the current ambition scenario, worldwide transport emissions are projected to grow by 60% by 2050, to 11 585 Mt. This increase drastically surpasses the 3 000 Mt that would likely be consistent with limiting global average temperature increase to well below 2ºC above pre-industrial levels.[2] The growth of transport CO_2 emissions between 2015 and 2050 in the current ambition scenario is driven mainly by domestic surface freight and non-urban passenger transport.

The more ambitious policies assumed in the high ambition scenario could reduce emissions from transport by 30% over the same time period, to 5 026 Mt. In 2050, projected emissions under the high ambition scenario are 57% lower than projected emissions under the current ambition scenario.

Figure 2.2. CO_2 emissions by sector and scenario for passenger and freight movements

Million tonnes



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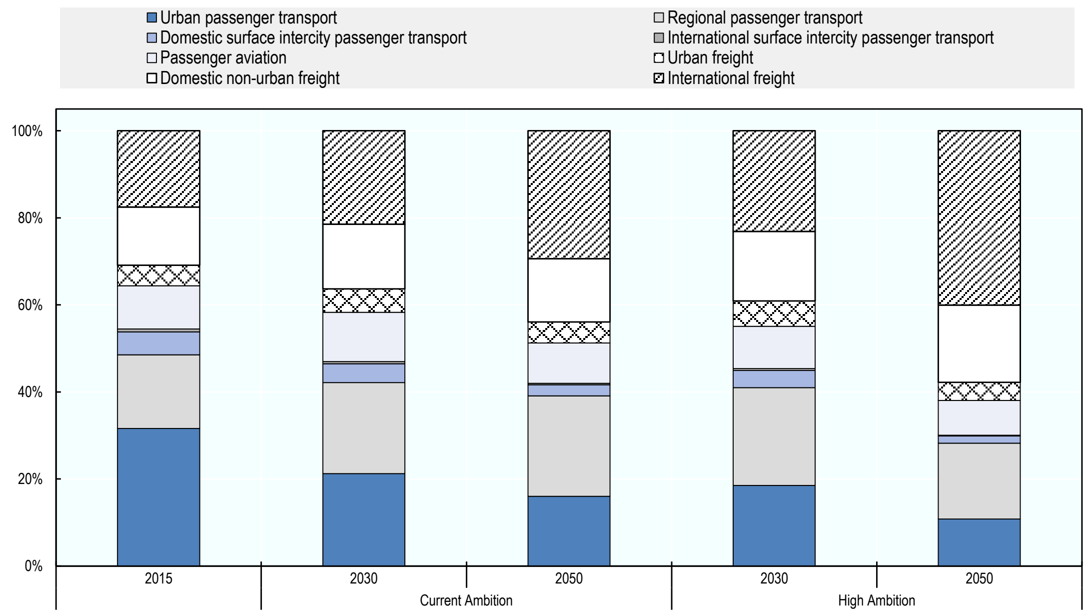
In the current ambition scenario, global CO_2 emissions are set to rise in all sectors except for urban passenger transport. Projections under this scenario see CO_2 emissions grow by 74% for non-urban passenger transport, 94% for domestic freight transport, and 157% for international freight. Emissions from urban passenger transport are projected to fall by 19%.

Total emissions fall under the high ambition scenario, but the level of reductions vary considerably across transport sectors. Urban passenger CO_2 emissions fall by 76% by 2050, while those for non-urban passenger transport drop by 42%. Emissions from domestic freight remain stable, partly because freight volumes grow substantially, cancelling out expected efficiency gains. Emissions from international marine and aviation activity rise by 59% between 2015 and 2050, even with the relatively ambitious mitigation measures assumed by the high ambition scenario.

Figure 2.3. Sectoral shares of transport CO_2 emissions by scenario

Percentages



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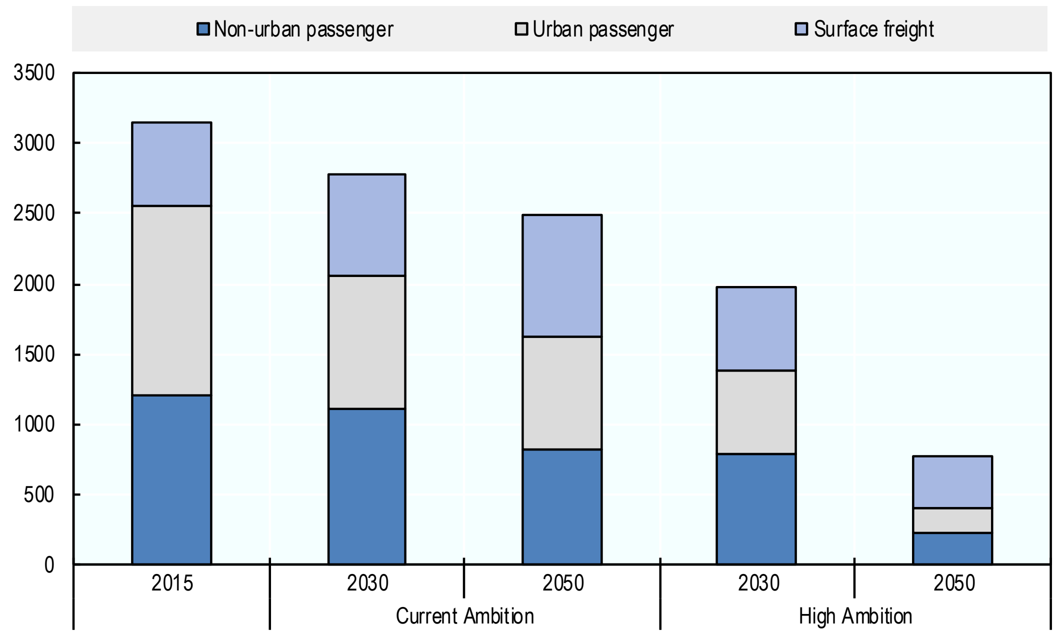
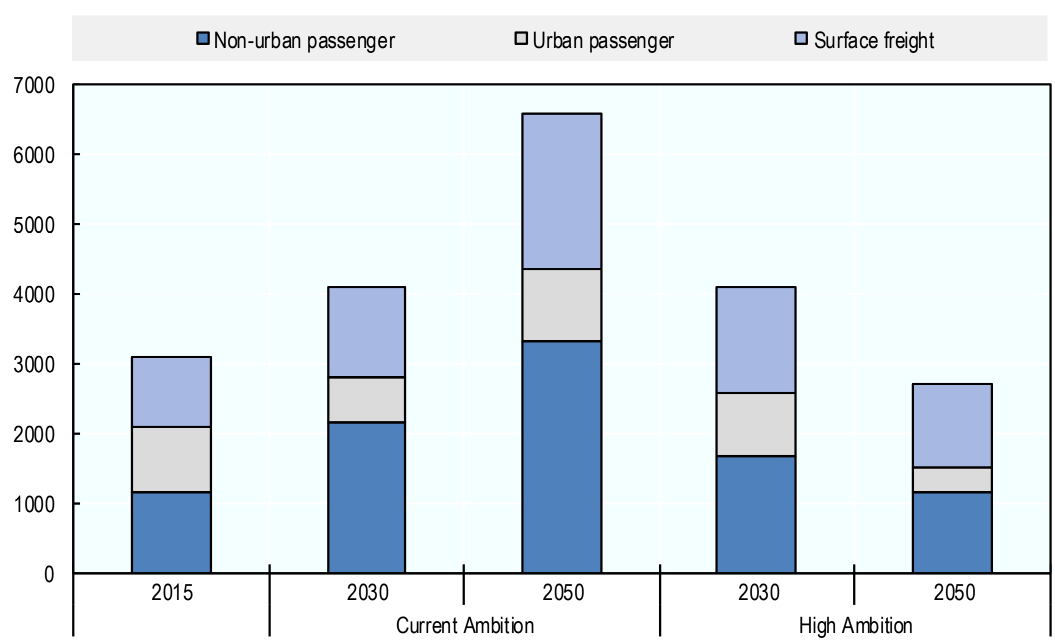
The sectoral composition of global transport CO_2 emissions shifts over time in both scenarios (Figure 2.3). Under current ambitions, emissions from domestic and international passenger aviation maintain the same relative share of total transport emissions through 2050. Emissions from domestic intercity passenger travel fall from 5% to 3%, while those from urban passenger transport decline from 32% of total emissions in 2015 to 16% in 2050. The share of emissions from regional passenger transport (i.e. road and rail travel) increases from 17% of total emissions in 2015 to 23% by 2050. Emissions from domestic non-urban freight (via road, rail, and inland waterways) increase by 2 percentage points over this period, accounting for 15% of emissions by 2050. Emissions from international freight increase significantly, from 18% to 29% between 2015 and 2050. The increased share of total emissions coming from regional passenger transport and from international freight reflects the fact that current policy portfolios focus on urban mobility relatively more than these sectors.

In the high ambition scenario, the share of emissions from passenger aviation remains stable through 2050, similarly to the current ambition projections. The share of emissions from domestic intercity passenger transport in the high ambition scenario declines further than in the current ambition scenario (to 2%). Emissions from urban passenger transport also decline, comprising 11% of total emissions in 2050. Emissions from regional passenger transport increase to 22% of total emissions by 2030 before returning to 17% by 2050. Emissions from domestic non-urban freight increase from 13% to 18% of total emissions between 2015 and 2050. The share of emissions from international freight transport rises from 18% to 40% of all transport-related CO_2 emissions between 2015 and 2050, again reflecting the relatively fewer mitigation measures that target international freight transport in the high ambition scenario.

Figure 2.4. Transport CO_2 emissions by sector and scenario

OECD countries (top) and non-OECD countries (bottom), million tonnes.





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Emissions projections under both scenarios differ significantly for OECD and non-OECD countries (Figure 2.3). In OECD countries, highly ambitious policies would accelerate a decline in emissions that is already expected in the current ambition scenario. In non-OECD countries, emissions under current ambitions are set to increase by 113% in 2050 relative to 2015. Even with more ambitious mitigation measures, emissions in non-OECD countries rise by 32% in 2030 before ultimately falling to 12% in 2050. In OECD countries, emissions are already projected to decline 21% by 2050 in the current ambition scenario, which increases to 76% in the high ambition scenario. This suggests that even if known measures are deployed to a greater extent than they are today, this will not curtail the growth in emissions associated with the strong projected increase in transport demand in non-OECD countries over the medium term.

More ambitious mitigation measures can cut emissions in urban areas

A series of complementary measures will be needed to enable sustainable modal shifts in urban passenger transport. Among them are the provision of high quality public transit systems and forward-looking, holistic urban planning. Car pricing policies, lower transit fares and improved vehicle technology could also contribute to a significant reduction of CO_2 emissions from urban passenger transport (ITF, 2018[15]). Land-use policies, transport planning and technological regulations are complementary and should be used in mutually reinforcing ways (ITF, 2017[16]).

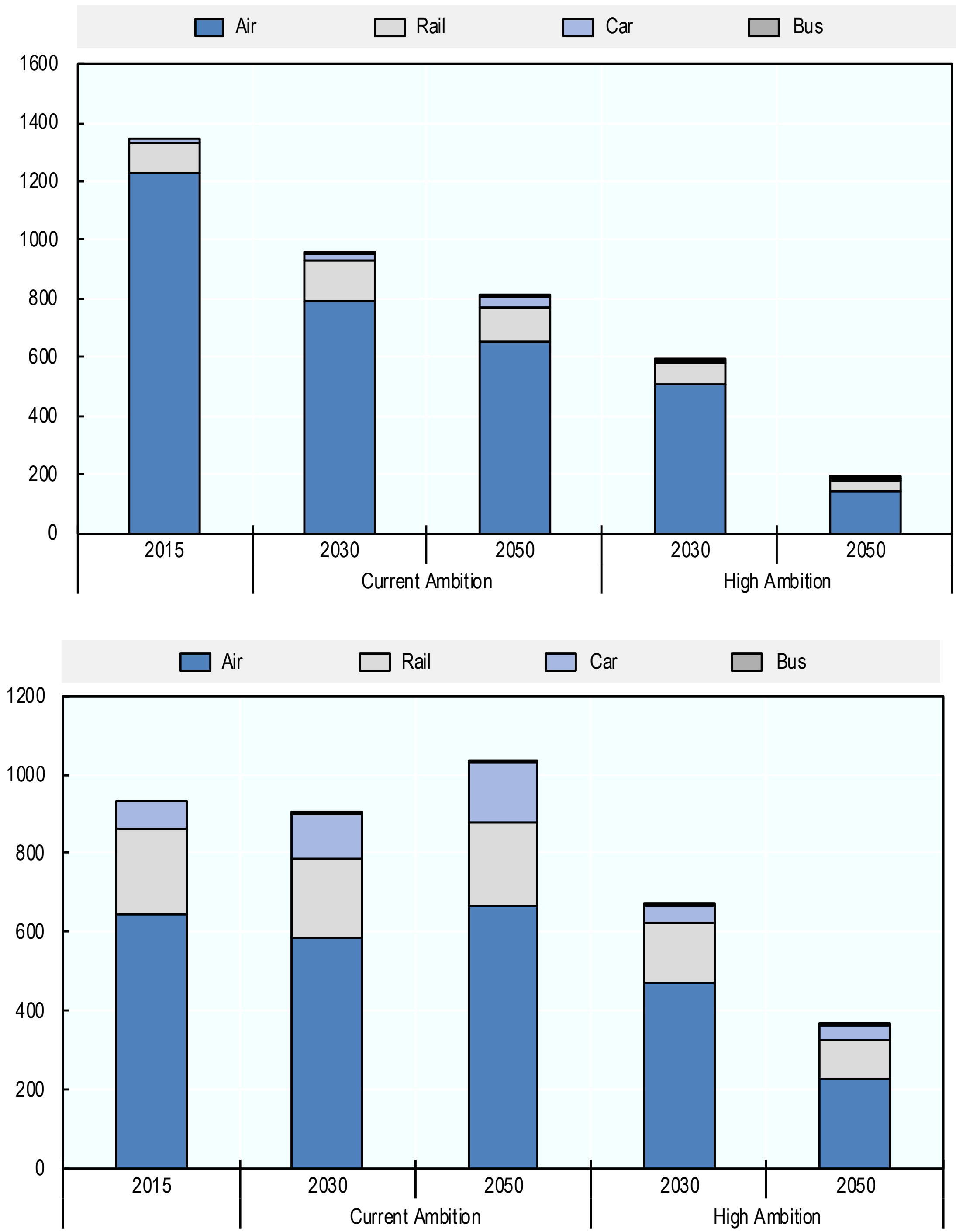
On the urban scale, the current ambition scenario broadly assumes a continuation of past trajectories. Current urban density levels are maintained in developed countries and fall slightly in developing countries. Car use in city centres is modestly reduced by 2050 and pricing disincentives regarding private car use continue to be implemented at current levels. Public transit networks increase capacity in line with population growth, a limited amount of shared mobility services are integrated with existing public transit networks, and uptake of autonomous vehicles is minimal. The market share of electric vehicles progresses along the trajectory foreseen by the IEA's new policies scenario (IEA, 2018[13]). The use of alternative fuels increases at a low rate, in line with current trends.

The more rigorous mitigation measures assumed in the high ambition scenario include a relatively rapid uptake of electric vehicles, following the projection of the IEA's EV30@30 scenario. Shared mobility services continue to be integrated with public transit as in the current ambition scenario. The uptake of autonomous vehicles remains marginal. Pricing disincentives reduce private car use more effectively, however, and more strategic land use planning and transit-oriented development lead to higher-density cities. In the high ambition scenario, greater restrictions are placed on car use in city centres. More details on the assumptions pertaining to urban passenger transport scenarios can be found in Chapter 3.

Global CO_2 emissions from urban passenger transport were estimated at 2 281 Mt in 2015. By 2050, emissions from urban passenger transport are projected to fall to 1 839 Mt per year in the current ambition scenario. In developed regions such as the European Economic Area (EEA), North America, and OECD Pacific, emissions from urban passenger transport are expected to decrease by 2050. In the high ambition scenario, total annual emissions from urban transport fall to 544 Mt by 2050. Figure 2.3 compares annual urban emissions in 2050 by world region in the current and high ambition scenarios. In all regions, the more aggressive mitigation measures assumed by the high ambition scenario dramatically amplify emissions reductions relative to the current ambition scenario.

Figure 2.5. CO_2 emissions from urban passenger transport by scenario

OECD countries (top) and non-OECD countries (bottom), million tonnes.



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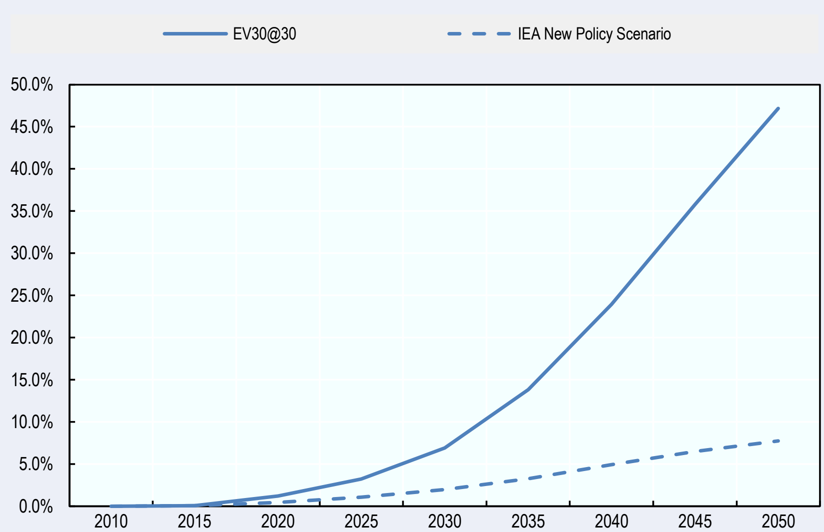
Box 2.1. Electrification of personal mobility

The electrification of personal mobility has accelerated dramatically over the past decade and constitutes one of the most effective and direct ways to reduce CO_2 emissions from passenger transport. Simulations of various scenarios estimate that the electrification of the global vehicle fleet will comprise about 30% of projected emissions reductions by 2050 (IEA, 2017[6]). Although electric vehicles (EVs) only constitute 0.2% of the current global vehicle stock (IEA, 2017[6]), the market has begun to gain momentum. In 2017, the sales of new electric cars worldwide surpassed one million for the first time (IEA, 2018[5]). Sales of electric two wheelers have also increased, reaching 30 million in the same year (IEA, 2018[5]). While China and the United States are two largest electric car markets in the world, Norway, Iceland and Sweden number among the countries with the highest market share of EV sales (IEA, 2018[13]). The adoption rate of EVs varies according to the type of technology (hybrid EVs, plug-in hybrid EVs, battery EVs, and hydrogen fuel cell EVs) but similar barriers exist across all EV technologies.

Figure 2.6. Global share of light duty electric vehicles by scenario, 2010-50

Percentages



Source: Data from IEA (2018[13])

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The proliferation of EVs will play an important role in reducing CO_2 emissions and meeting sustainable development goals. To this end, the Clean Energy Ministerial Electric Vehicle Initiative has set the goal of reaching a 30% share for new EV sales by 2030 (EV30@30). The Paris Declaration on Electro-Mobility and Climate Change has also set an objective of obtaining a fleet of 400 million electric two/three-wheel vehicles and 100 million electric vehicles by 2030.

The transport sector was responsible for approximately 2% of electricity use in the world in 2017, but electric vehicles are expected to increase use to five times current levels by 2040 (IEA, 2018[13]). The IEA new policies scenario (NPS) predicts that there will be almost 130 million electric vehicles (excluding two/three-wheelers) in circulation by 2030 (IEA, 2018[5]). According to the NPS, EVs will make up 2% of all light duty vehicles by 2030 and 7.7% by 2050 (Figure 2.6). However, the projections of EV30@30 are much higher, estimating the share of electric light duty vehicles to be nearly 7% by 2030 and over 47% by 2050. The primary drivers of this change are political commitments made by cities, regions and countries in support of electrification. The automobile industry will also contribute to the expected increase in the number of EVs worldwide by providing diverse EV options at different price points.

The main factors that could determine the future uptake of EVs include the technological readiness and cost effectiveness of EV components over time and consumer satisfaction regarding characteristics such as range and charging time. While significant progress has been made in developing batteries for EVs, major challenges remain. Technological barriers are mostly associated with the pace of battery development (Tollefson, 2008[17]). Current batteries are characterised by relatively low energy densities, making large and heavy batteries necessary in order to ensure adequate operational ranges. Along with technological advancements, battery costs must decline significantly if EVs are to become competitive in the marketplace. Technological improvements are expected to reduce battery price to below USD 500/kWh by 2020 (Mahmoudzadeh Andwari et al., 2017[18]), but this is still higher than the estimated optimal price level of USD 150/kWh (Burke, 2007[19]), or under USD 200/kWh (Delucchi and Lipman, 2001[20]). Other barriers include reducing the total cost of ownership, safety improvements, lifespan expansion, shortening of charging time and the provision of more extensive charging facilities (Pollet, Staffell and Shang, 2012[21]).

Measures that encourage EV sales have been widely implemented in Europe, especially in Germany, the United Kingdom, Spain, Denmark, France, and Norway, as well as in the United States, Japan, China, and India. Policies to encourage EV uptake can be grouped into two general categories: one that aims to increase demand for EVs and the other that focuses on the provision of infrastructure that supports EV use (Leurent and Windisch, 2011[22]). Policies that address vehicle demand include purchase subsidies, taxation incentives, lower insurance costs, reduced or no parking fees, the use of priority or public transport lanes, free use of services and facilities, and free public transport for EV owners. With respect to infrastructure deployment, countries usually focus on providing subsidies, public financing, or tax reductions for the development of EV infrastructure (Leurent and Windisch, 2011[22]).

The impact of such incentives on actual EV sales will depend on existing travel patterns and mode shares, public willingness to change travel behaviours and demand elasticities. Financial incentives tend to be more effective than measures related to priority lane use and free parking (Sierzchula et al., 2014[23]; Lieven, 2015[24]). Most governments continue to be reluctant to invest in charging infrastructure but to implement financial incentives instead (Lieven, 2015[24]), which will hinder widespread uptake of EVs in the long term (Dernbach and Tyrrell, 2010[25]). Electricity production and the increase in demand will also need to be considered. In addition, there is an urgent need to decarbonise electricity generation that will require massive investment in renewable energy generation capacity and new infrastructure development.

Urban transport emissions in developed countries are already projected to decrease by 40% by 2050 if countries follow current policies. Enhanced political ambition would significantly accelerate the decarbonisation of urban transport, reducing emissions by 86% over the same period. In non-OECD countries, emissions from urban passenger transport are projected to increase by 10% by 2050. More ambitious mitigation measures, however, would reverse this trend, yielding projected emissions decrease of 61% by 2050.

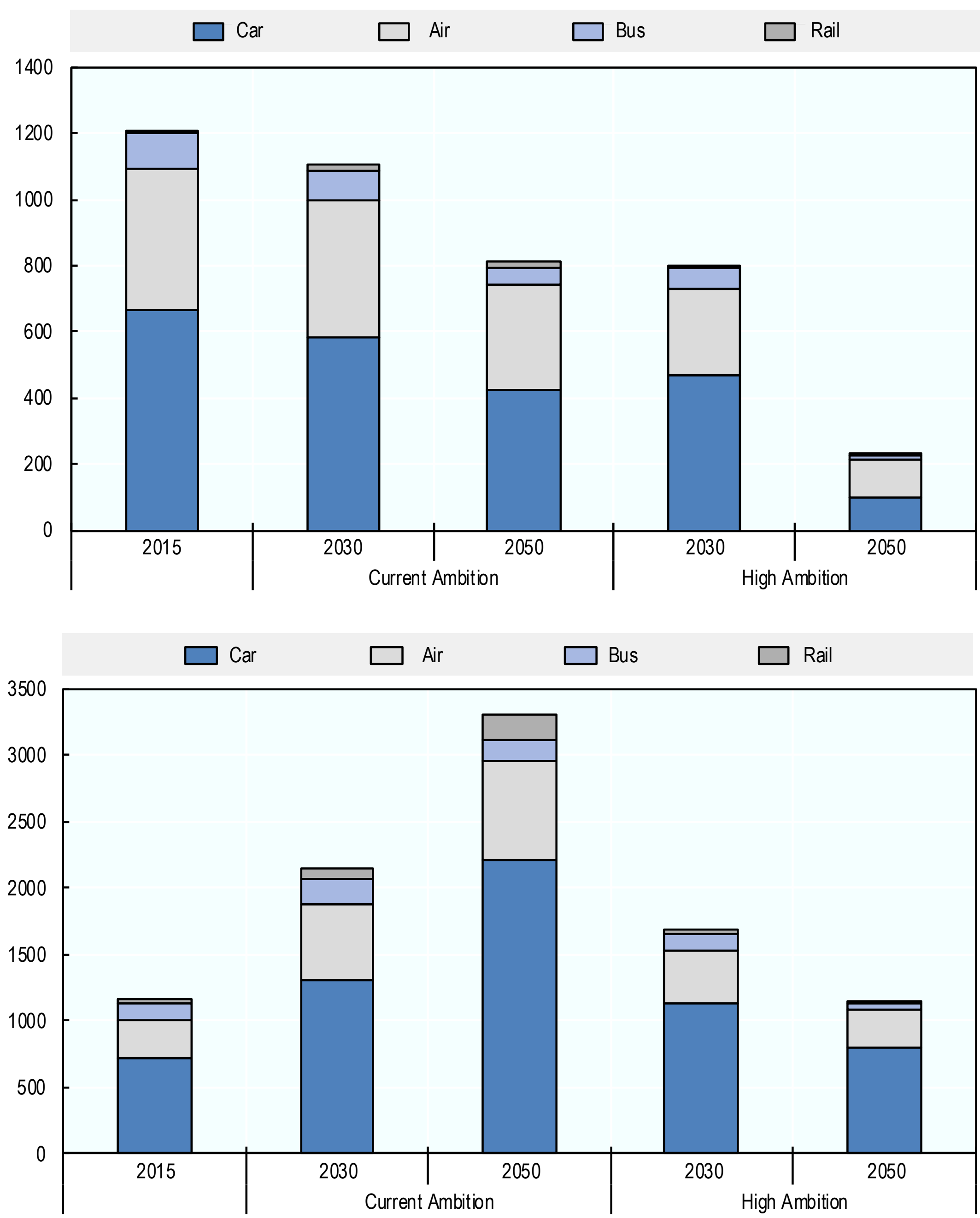
Greater mitigation ambitions can attenuate expected increases in emissions from non-urban passenger transport

Non-urban passenger transport comprises inter-urban transport and intra-regional transport, i.e. all regional transport activity that falls outside of urban and international transport. Non-urban transport relies on personal vehicles, busses, trains, and aircraft. Demand growth for personal vehicle and air travel is the main driver of non-urban passenger transport emissions, as these modes are significantly more carbon intensive per passenger-kilometre than rail travel.

Electric vehicle technology offers a promising pathway for decarbonising passenger road travel. For the aviation sector, this option is more limited. There are only few commercially viable alternatives to fossil fuel in aviation today, and rapidly rising demand for air travel will make mitigation efforts in the sector a particular challenge. Reducing aviation emissions is further complicated by the fact that these emissions are not confined by national borders. For this reason, aviation emissions are not covered under the Paris Agreement. Instead, the International Civil Aviation Organization (ICAO) has been working with its member countries to agree measures that will limit aviation's contribution to climate change. These measures range from operational efficiency improvements to the introduction of a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Figure 2.7. CO_2 emissions from domestic non-urban passenger transport by mode and scenario

OECD countries (top) and non-OECD countries (bottom), million tonnes



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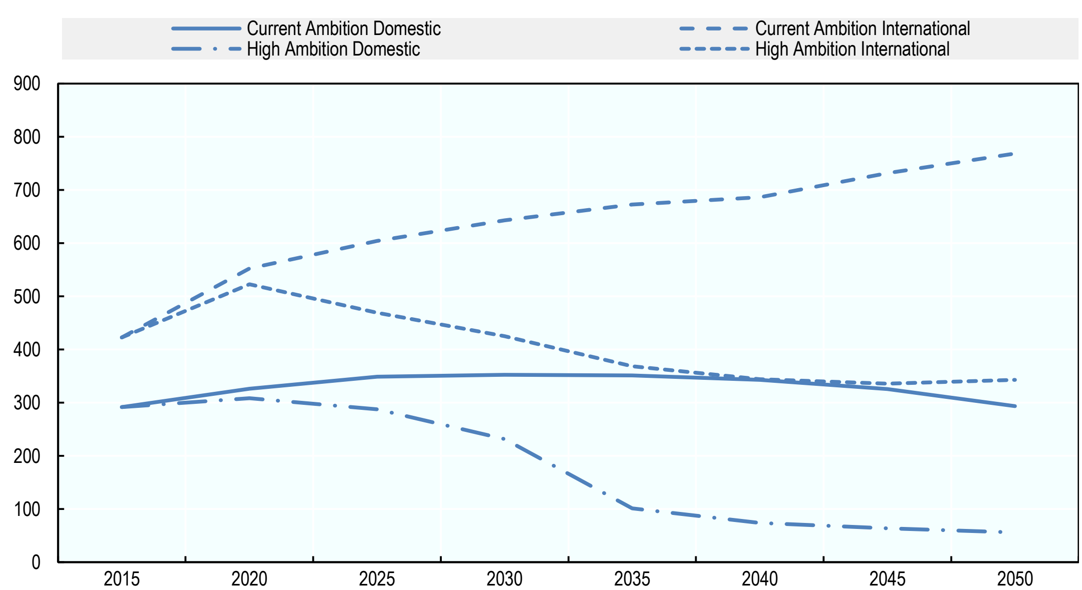
The current ambition scenario in non-urban passenger transport reflects business-as-usual assumptions regarding mitigation efforts, including a moderate increase in carbon pricing by 2050. Technological developments such as improvements in the fuel efficiency of vehicles and aircrafts follow the IEA's new policies scenario. The high ambition scenario reflects accelerated improvements in vehicle fuel efficiency and a substantial increase in the intensity of carbon pricing by 2050

Under current ambitions, emissions from non-urban passenger transport are projected to decline by 40% in OECD countries by 2050. In non-OECD countries, in contrast, emissions are projected to rise by nearly 181%. Most of the growth in CO_2 emissions from non-urban passenger transport will come from car travel (+211%) and air travel (+157%) between 2015 and 2050. In the high ambition scenario, the implementation of more ambitious mitigation measures amplifies the expected decrease in emissions in OECD countries, which would fall by 81% by 2050. They also largely attenuate the emissions increase in non-OECD countries, which would still be higher in 2050 than in 2015, but only by 11%. The unbroken growth trajectory of CO_2 emissions from non-urban passenger transport in the non-OECD countries under the current ambition scenario reflects a sharp rise in demand in these countries.

In aviation, aircraft operators will collectively offset, or compensate for, CO_2 emissions that surpass a threshold based on the average of 2019/20 emissions under CORISA. Following a trial phase between 2021 and 2023 and a voluntary phase between 2024 and 2026, participation will become mandatory, with a few exceptions for instance for least-developed countries. As a global, sector-wide emissions-reduction mechanism, CORSIA is one of the first of its kind and is intended to prevent emissions from international aviation from growing after 2020 even if demand for air travel rises.

Figure 2.8. CO_2 emissions from domestic and international aviation by scenario

Million tonnes of CO_2 emitted, before offsets



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In the current ambition scenario, total emissions from passenger aviation are projected to rise nearly 50% by 2050, driven entirely by international aviation activity. Emissions from international passenger aviation are projected to rise by 82% over this period, while emissions from domestic passenger aviation are projected to remain stable. The growth in emissions shown in Figure 2.8 does not take into account the carbon offsets that will be required under CORSIA, which are designed to keep the international aviation sector on a carbon-neutral growth path after 2020 relative to average emissions of the sector in the years 2019-2020. In the high ambition scenario, CO_2 emissions from international aviation decrease by 19%, while overall emissions from domestic aviation decrease by 81%. This reduction would be made possible by an assumed electrification of short-haul flights and more stringent carbon pricing.

More ambitious mitigation measures can largely avert projected increases in freight emissions

With respect to freight transport, the current ambition scenario reflects existing policies and regulations, technological advances in line with the new policies scenario of the International Energy Agency (IEA), and projections of international trade activity to 2050 according to the OECD ENV-Linkages model (Château, Dellink and Lanzi, 2014[14]). The elasticity of trade to GDP remains relatively low in this scenario (ITF, 2017[16]).

The high ambition scenario for freight, on the other hand, assumes a more comprehensive electrification of surface freight transport along the lines of the IEA's EV30@30 scenario. It also posits that less demand for fossil fuels will results in a lower volume of trade in these commodities relative to today. Oil, gas and coal together comprised 41% of total international seaborne trade in 2016 (UNCTAD, 2017[26]). A significant reduction of these volumes would have a sizeable impact on international freight flows.

The high ambition scenario thus assumes a gradual reduction in global coal and oil trade which cuts coal trade volume by 50% and oil by 33% by 2035, equivalent to annual declines of 3.35% for coal and 2.1% for oil. These reduction factors are similar to those assumed in the Representative Concentration Pathway 2.6 scenario of the International Maritime Organization (IMO), which projects a decline of about 48% in transport demand for coal trade and 28% for liquid bulk trade, including oil over the same period.

Overall, the mitigation measures implemented in the high ambition scenario are able to cut global emissions from freight transport in 2050 by 45% relative to the current ambition scenario. Figure 2.9 shows that the majority of these emissions reductions come from road and maritime freight transport. Emissions from air freight remain nearly identical in 2050 across the current and high ambition scenarios due to strong rising demand for air freight transport as well as limited existing decarbonisation options in the aviation sector.

Figure 2.9. Projected CO_2 emissions from international freight by mode, 2015-50

Current and high ambition scenarios, million tonnes

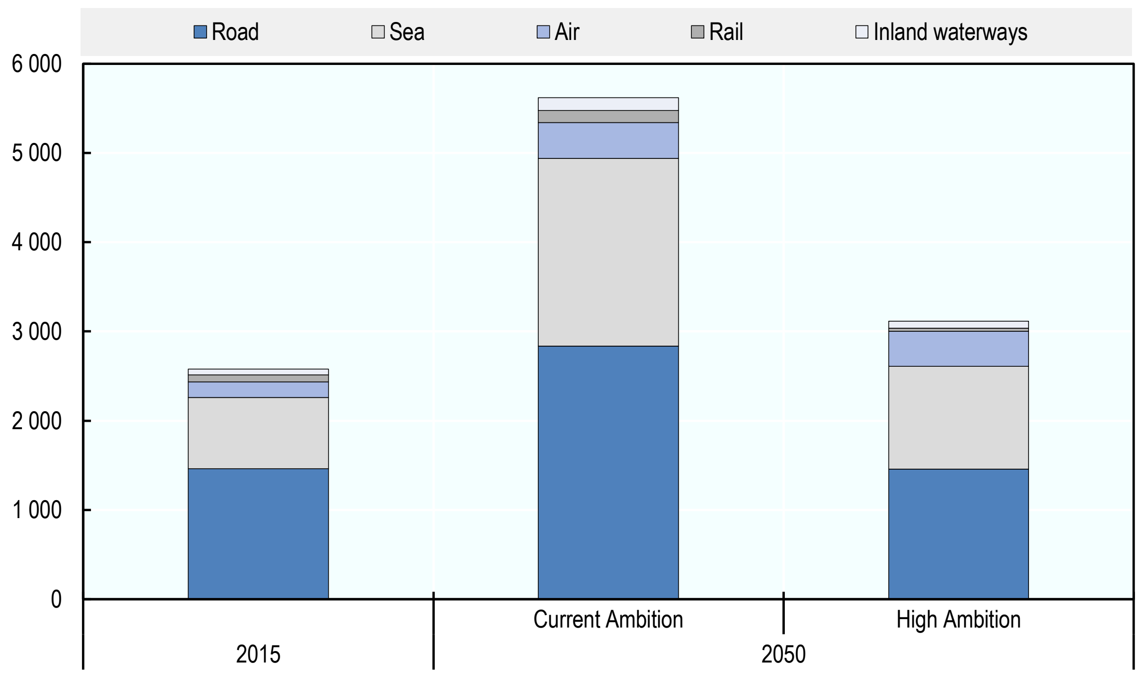

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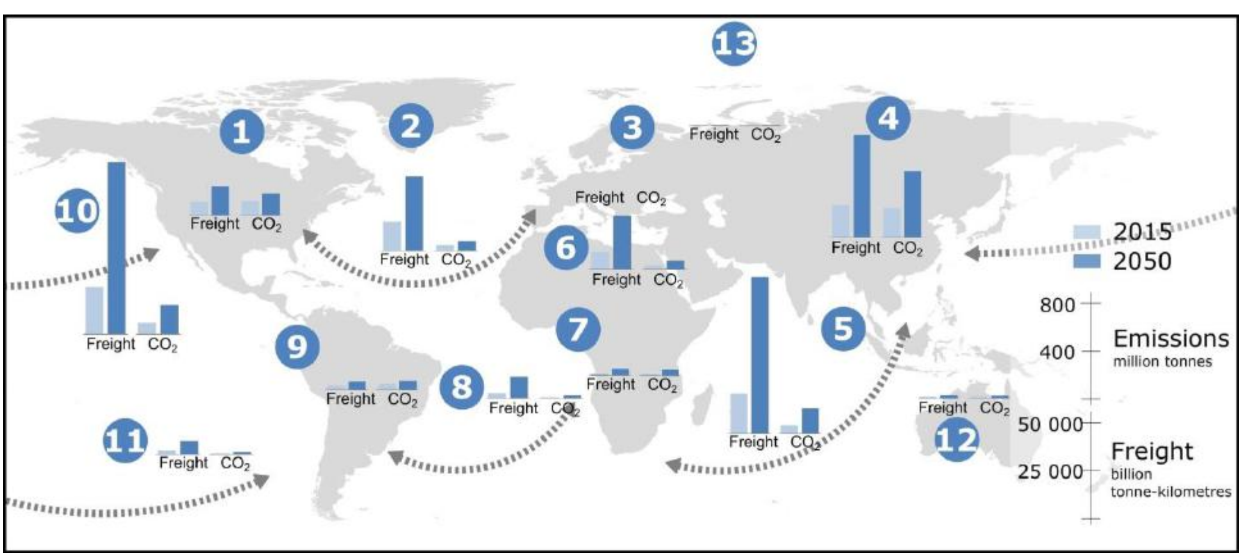
Figure 2.10. Projected international freight flows and related CO_2 emissions

Current and high ambition scenarios by corridor



Note: 1. North America; 2. North Atlantic; 3. Europe; 4. Asia; 5. Indian Ocean; 6. Mediterranean and Caspian seas; 7. Africa; 8. South Atlantic; 9. Latin America; 10. North Pacific; 11. South Pacific; 12. Oceania; 13. Northern Sea Route.

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Demand for freight transport rises significantly for all corridors by 2050 in both the current ambition and high ambition scenarios. Expected freight volumes do not differ greatly between scenarios, indicating that the mitigation measures assumed in the high ambition scenario have a limited impact on freight transport demand. Freight flows to Asia, from Asia, and within Asia are expected to grow most. Figure 2.11 shows that CO_2 emissions from surface freight increase on all continents under current mitigation ambitions, and particularly from road freight transport.

In the current ambition scenario, emissions from surface freight transport rise by 39% in OECD countries and by 122% in non-OECD countries by 2050. In the high ambition scenario, emissions in OECD countries fall by 44% over this period, whereas emissions in non-OECD countries nevertheless increase by 16%. This is due to the fact that demand for freight transport outstrips improvements in technological and logistical efficiency in non-OECD countries. In OECD and non-OECD countries alike, the majority of CO_2 emissions from surface freight are generated by inter-urban road transport. The emissions reductions in inter-urban road transport achieved in the high ambition scenario are made possible by the assumption of high fleet electrification rates and the decarbonisation of the energy sector.

Figure 2.12 shows that the measures undertaken in the high ambition scenario enable a significant reduction in the CO_2 intensity of road freight beyond that achieved in the current ambition scenario. The average global road freight intensity falls by 63% by 2050 in the high ambition scenario vs. 26% in the current ambition scenario. Stalled decreases in emissions per vehicle-kilometre in several regions in the current ambition scenario are due to an increase in the use of heavy trucks for non-urban transport. A more detailed discussion of travel demand by mode for each of these scenarios is provided in Chapter 5.

Figure 2.11. Projected CO_2 emissions from surface freight by mode and country grouping

Current ambition (top), and high ambition (bottom), million tonnes.

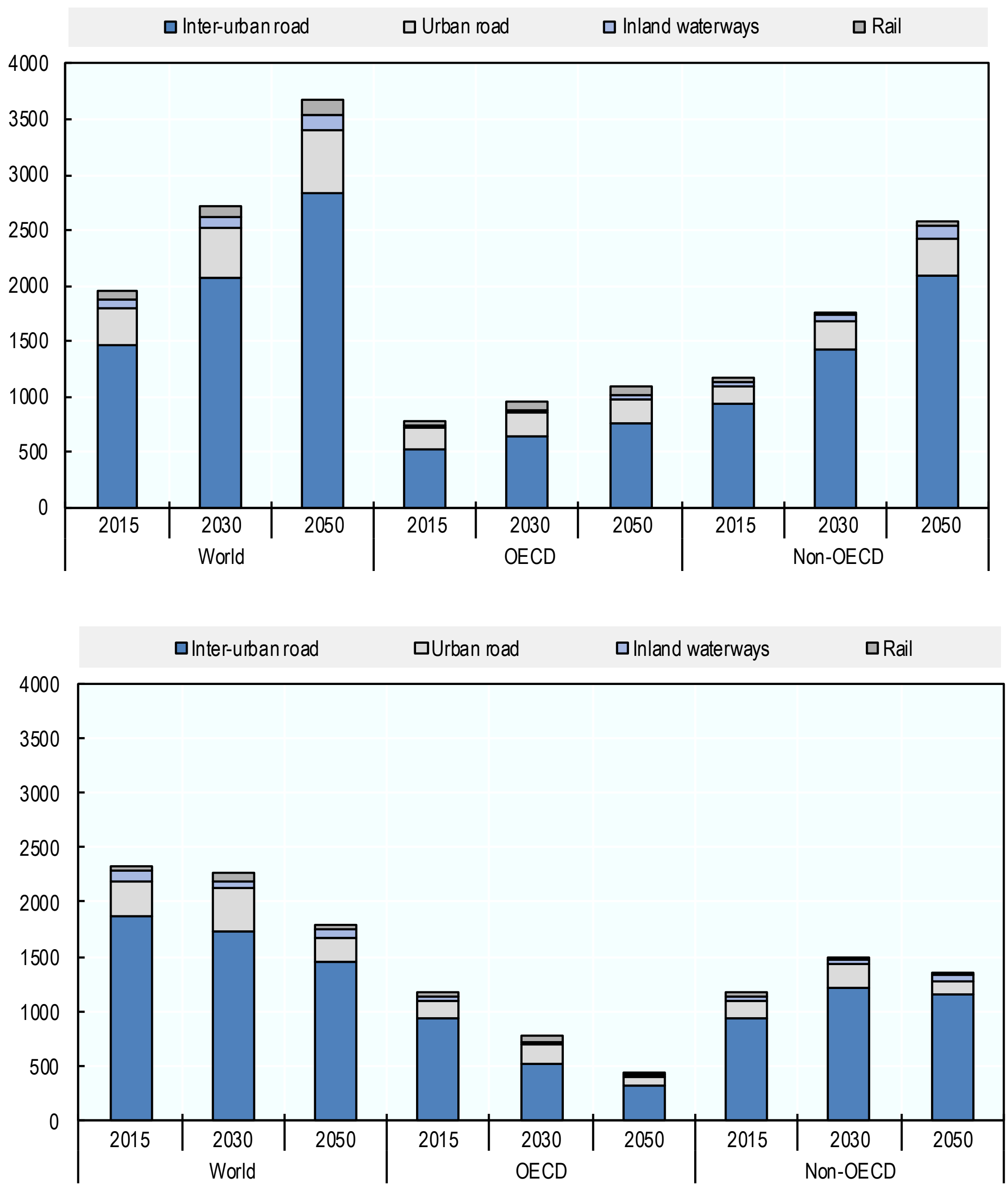

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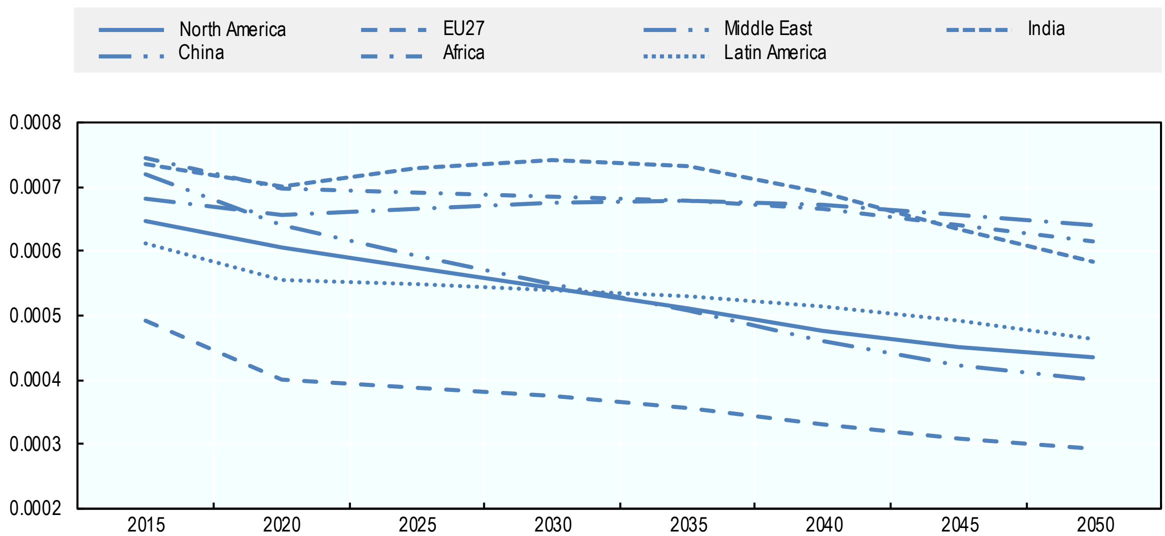
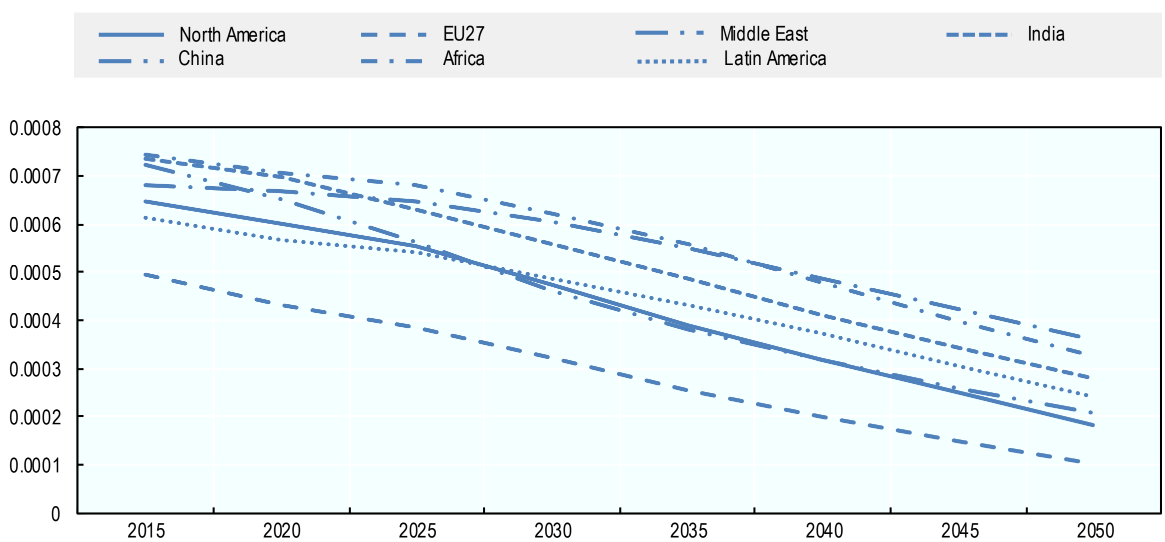
Figure 2.12. Road freight CO_2 intensity by region and scenario

Current ambition (top) and high ambition (bottom), tonnes of CO_2 per vehicle-kilometre.





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Box 2.2. The ITF Decarbonising Transport Initiative

The signature of the Paris Agreement in December 2015 created a political pathway for climate change mitigation efforts by setting up a five-year review cycle for national decarbonisation commitments starting in 2020. The International Transport Forum's Decarbonising Transport initiative directly responds to the needs of global actors to identify effective policies for CO_2 reduction in the transport sector.

The Decarbonising Transport initiative promotes carbon-neutral mobility to help stop climate change. It provides decision makers with tools to select CO_2 mitigation measures that deliver on climate commitments. The initiative does not advocate specific measures or policies. Building on an evidence-based assessment of mitigation impacts, it identifies options for decisionmakers to achieve targets, such as those set in the Nationally Determined Contributions as well as targets set by sectors, companies or cities.

The assessments of the Decarbonising Transport initiative are grounded in data analysis and advanced modelling. Uniquely, the ITF modelling framework derives projections of transport activity by analysing the drivers of transport demand. It then models how changes in mobility patterns affect transport CO_2 emissions. More specifically, the Decarbonising Transport initiative is organised into five work streams:

- *Tracking progress*: The initiative evaluates how current mitigation measures contribute to reaching objectives for reducing transport CO_2.
- *In-depth sectoral studies*: The initiative identifies effective policies for decarbonising urban passenger transport, road freight transport, maritime transport, aviation and non-urban transport.
- *Focus studies*: The initiative analyses specific decarbonisation issues and feeds the results into other work streams.
- *National pathways*: The initiative assesses available policy levers for decarbonising transport from a country perspective. Projects may also examine regional or sub-national levels.
- *Policy Dialogue*: The initiative organises global dialogue on transport and climate change through high-level roundtables, policy briefings and technical workshops. It acts as a conduit for transport sector input to climate change negotiations.

The Decarbonising Transport initiative brings together more than 70 governments, organisations, institutions, foundations and companies. Partners contribute in different roles including as funders and knowledge partners. The initiative was launched in 2016 with core funding from the ITF's Corporate Partnership Board (CPB). Other funding partners currently include the national governments, universities and research institutes, intergovernmental organisations, multilateral development banks, professional and sectoral associations, cities and regions, non-governmental organisations, and philanthropic foundations.

In recognition of the work of its Decarbonising Transport initiative, the UN Climate Change Secretariat (UNFCCC) has named the International Transport Forum as a focal point for transport under its Marrakech Partnership. In this role, the ITF acts as a conduit for the exchange of information between the transport sector and the UNFCCC, as well as providing inputs to the UNFCCC process. More information at: www.itf-oecd.org/dt

Disruptive innovations will be needed in order to achieve decarbonisation targets in the transport sector

Projections of transport-related CO_2 emissions suggest that the more aggressive deployment of known mitigation measures could reduce the sector's annual emissions from 7 230 Mt in 2015 to 5 026 Mt in 2050. This amounts to a decline of 30% and a significant reduction relative to the level of CO_2 emissions that would ensue in 2050 if ambitions remained as they are today (11 585 Mt). Yet even this decrease would fail to deliver the magnitude of CO_2 reductions that is required in order maintain global average temperatures to well-below 2ºC above pre-industrial levels. Innovative, indeed disruptive, strategies will be needed to shift the trajectory of transport-related emissions below that attained in the high ambition scenario. Critically, the strategies employed to do so must find a way to curb emissions while simultaneously meeting rapidly growing demand for passenger and freight mobility alike.

A number of factors could disrupt current transport patterns and future emissions trajectories. Some of these depend largely on actions taken by policy makers, for instance measures to encourage the uptake of shared mobility or autonomous vehicles. Others are driven by forces largely outside the transport sector, such as the rise of e-commerce or changing international trade patterns. Whether policy-driven or exogenous, how exactly these disruptive developments unfold will have important consequences for the future of transport. Importantly, the impact that exogenous factors will have on transport demand and emissions will depend in part on how policy makers choose to manage them. Transport policies will need to be responsive to disruptive developments in a broad range of areas in order to reap their potential benefits and minimise any negative impacts.

The modelling simulations presented in the following Chapters explore the potential for a number of possible developments to disrupt future transport demand and transport-related CO_2 emissions in the urban passenger, non-urban passenger, and freight transport sectors. These simulations aim to better understand the direction and magnitude of the impacts that these disruptive developments may have, as well as the role that transport policies can play in managing how exogenous developments will ultimately shape transport systems in the future.

In a sector poised for change, it is incumbent on transport policy makers to endeavour to anticipate the changes to come, but also – and perhaps more importantly – to determine how they plan to respond to these changes. This task is compounded by the considerable uncertainty surrounding the nature of potential developments and their impact on transport patterns, as well as the mounting urgency to decarbonise the sector. The projections presented in the *ITF Transport Outlook 2019* are intended to contribute to a forward-looking policy dialogue in the context of the continued global pursuit of sustainable mobility.

Notes

[1] This is broadly in line with the IEA estimate of 7 738 Mt of transport-related emissions in 2015.

[2] These figures reflect tank-to-wheel (TTW) emissions, and so omit the indirect well-to-tank (WTT) emissions that are produced in the extraction, refinement, and transportation of fuels before they are used. Indirect emissions make up a varying proportion of total emissions depending on the fuel type and vehicle technologies considered. In one study, for example, indirect TTW emissions

from road freight in Europe accounted for about 28% of total WTW emissions in the road freight sector in 2005 (ICCT, 2016[29]).

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Chapter 3. Disruptions in urban passenger transport

This chapter reviews the current landscape of urban passenger transport, including a number of technological and business developments that disrupt the sector in the future. It develops two main disruptive scenarios: one that portrays a future in which policy adjustments are made to manage the disruptive effects of these developments and one in which no such adjustments are made. The results indicate that disruptive developments may lead to modal shifts that increase congestion and emissions by 2050, and that targeted policies will be necessary in order to steer these developments in directions that minimise their negative externalities and maximise their co-benefits.

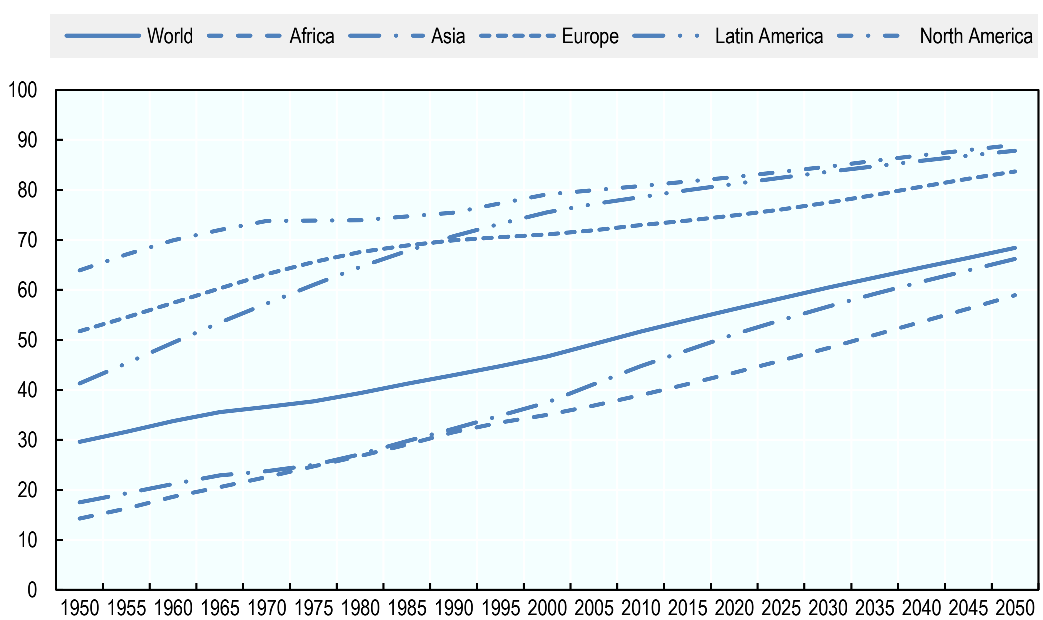
The urban mobility landscape is rapidly changing

Most trips today take place in urban regions, and their number is projected to continue to grow in line with cities' population and gross domestic product (GDP). Worldwide, urban regions face both constraints and opportunities with respect to mobility. The limits of the current mix of transport solutions will be most strongly felt in cities. On the other hand, urban areas will be fertile ground for game-changing transport innovations. This push and pull is not new. Innovation under constraints has always been a force for systemic change, and the transport sector is no exception. Today, the innovation cycle is accelerating again, with a rapid convergence of disruptive technologies, business models and services, notably in urban areas. This convergence is particularly visible in urban mobility, but extends across many other areas of the economy and society.

Will these disruptive developments take hold and, more importantly, will they reach a sufficient scale? If they do, tomorrow's transport may well operate under a different socio-technical regime from the one that characterises urban mobility today. For cities, it will be critically important to understand the conditions that would bring about such disruptions identify their potential impacts and reflect on how policy can guide and manage them.

Figure 3.1. Share of population residing in urban areas by region, 1950-2050

Percentages



Source: UN DESA (2018[1])

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Change across the wide range of urban settings worldwide will not be uniform. Different policy, economic, social or geographical contexts mean innovations will play out differently in different urban settings. What may prove to be disruptive in Beijing or Los Angeles may be less impactful in Brussels or Lagos. Likewise, the timing and duration of disruptive effects may differ from city to city and from country to country.

Finally, these disruptions will generally confer immediate benefits to those that take advantage of them – and especially to those that do so early. However, from the societal perspective their aggregate impact may be positive, negative or inconsequential. There is a clear role in proactive policy to ensure that the action of public authorities guide disruption in order to maximise benefits and minimise negative outcomes. This, of course, is difficult to do when the disruptive trends first emerge as weak outlier signals before they gain traction and scale up.

The context-specific characteristics of different urban areas and the very nature of disruptions themselves make it difficult to predict the pathway of disruptive developments. This *Transport Outlook* examines three plausible and potentially disruptive developments in isolation, as well as in combination with each other, in various scenarios.

The three disruptive developments for urban mobility examined in this chapter are:

1. A widespread adoption of teleworking and telepresence more broadly;
2. A significant increase of automated and autonomous driving in cities;
3. Massive uptake of shared and optimised mobility services.

Leaving aside telework, these disruptive developments do not rely on a fundamental change in the basic vehicle technology underpinning the urban mobility eco-system. Autonomous driving and widespread shared mobility will continue to rely on vehicles operating on city streets and on rails. These vehicles more or less resemble today's fleets of cars, vans, buses, trains, bicycles and various forms of motorised single-person vehicles. The scaling-up of these two disruptive developments may be made easier by the fact that they do not call into question the current socio-technical system built around the construction, maintenance, fuelling, insuring and licensing of vehicles. Of course, both disruptions, individually and taken together, imply a significant shift in the ways in which vehicles are used and in the business models and travel behaviours that may emerge with their development. Telework and telepresence, on the other hand, could eliminate some transport activity and replace the socio-technical system that supports it with another configuration based on virtual presence.

A common feature of the three disruptions is their reliance on computer and communication technology, information and data – and the emergence of new business models enabled by digitalisation. With regard to teleworking, the meaningful and productive virtual presence of workers requires ubiquitous network technologies and systems.

With respect to autonomous driving, replacing human drivers with algorithm-led and artificial intelligence-based control systems requires the development and deployment of skilful sensing-processing-actuator technologies and opens up new fields for industrial production and commercial service development. This will also induce changes in support activities such as law, insurance, coding and design. Autonomous vehicles may improve safety and reduce cost for fleet operators, potentially leading to new service delivery models that could be tied to shared mobility services or Mobility as a Service (MaaS) packages.

Likewise, these disruptions will improve supply-demand matching and seamless integration across modes enabling the widespread uptake of new mobility services. These have the potential to affect travel costs, thereby reshape users' mode choices and ultimately lead to new travel patterns. A massive uptake of shared mobility services, supported by MaaS, holds particular potential for shifting two fundamental and persistent paradigms in the provision of current urban mobility services: the ownership of private transport and "scheduling" of public transport. New models of mobility would enable on-demand, optimised sharing of vehicles and seamless mixing of modes and allow mobility providers to better target the needs and desires of individual travellers.

All three disruptions face a formidable hurdle: the ever-compelling model of private, car-based mobility. How far the disruptive trends will be able, alone or in combination, to drastically shift the status quo will depend on the constraints travellers face in the current mobility system, the extent to which regulatory frameworks encourage or hinder new mobility models, and finally the relative costs of new mobility services compared to those currently available (and how these costs evolve over time).

The mitigation potential of urban transport policies

The urban passenger transport model developed by the International Transport Forum (ITF) assesses transport activity, mode shares and related emissions under various policy scenarios for all urban areas with a population above 50 000 inhabitants across all world regions up to the year 2050.[1] This model framework is constantly evolving as new data sources are incorporated and analytic methods improved. Box 3.1 highlights the most recent enhancements to this model.

Box 3.1. Recent enhancements to the ITF urban passenger model

The ITF's urban passenger model was presented in 2017 (ITF, 2017[2]). Since then, the model has been enhanced in several ways. The main model updates were:

1. *Improved representation of different transport modes and their interaction*: now included are shared mobility services (i.e. services with a driver, where people share the same vehicle for at least a part of their trip, such as shared taxis and mini-buses) as well as shared vehicle systems (i.e. shared cars, shared bikes, shared motorbikes, and shared scooters, where users do not necessarily share their trip with anyone else). Also now included is an integration parameter that reflects the ease of changing between different means of transport, e.g. between new and conventional transport modes.
2. *Refined GDP and car ownership estimates*: these are now city-specific instead of country-specific.
3. *More detailed representation of small urban areas*: (50-300 000 inhabitants) is made possible by introducing a new category of "small cities". Mode share patterns for small cities are different from those of larger cities, reflecting for example the fact that small cities often do not have mass transit services

Two urban mobility scenarios were developed for this *Transport Outlook*, a current ambition scenario and a high ambition scenario (see Table 3.1 for scenario specifications). Ambition in this context reflects the effort undertaken by stakeholders to reduce CO_2 emissions and introduce respective CO_2 mitigation policies. Each scenario delivers expected increases in the demand for urban mobility in different ways (Figure 3.2), which has a significant impact on resulting CO_2 emissions in the sector across scenarios (Figure 3.3). Later on in this Chapter, additional scenarios that assess the impact of potential disruptive developments on travel demand and related CO_2 emissions are explored.

The current ambition scenario for urban passenger transport

The current ambition scenario is characterised by a continuation of current urban transport policy portfolios, including announced policies that are set to take effect in future years (Table 3.1). In the current ambition scenario, technological advancements and the uptake of autonomous and shared mobility occur at a moderate pace. The electrification rate of urban vehicle fleets is in line with the New Policies Scenario (NPS) of the International Energy Agency (IEA, 2018[3]). Transport modes are integrated only to a limited degree; there are still significant barriers to seamless travel across different transport modes for urban travellers. The supply of public transport develops in line with historical trends. The density of urban areas does not change dramatically, although urban sprawl continues in some regions.

Based on recent trends, some cities in the current ambition scenario implement car restriction policies in the urban core supported by corresponding parking policies to tackle increased congestion and pollution. The policy measures assumed in this scenario are already more stringent than those in the baseline scenario presented in the 2017 *Transport Outlook* (ITF, 2017[2]). This reflects an increased awareness of the challenges related to urban passenger transport and the impact of recent and forthcoming mitigation measures that cities have been taking as a result. Overall travel activity grows in line with the GDP and population projections. The increased uptake of teleworking somewhat slows the growth of passenger-kilometres travelled, resulting in a growth of total passenger-kilometres in urban areas by 38% by 2030 and by 104% to 2050 compared with 2015.

The share of urban passenger-kilometres travelled in private vehicles (including individual taxi services) declines from around 70% in 2015 to 40% by 2050 in the current ambition scenario. Shared modes[2] that include shared vehicles systems (e.g. free-floating or non-free-floating shared cars, bikes or scooters)[3] and optimised shared mobility services (e.g. a shared taxi, van or minibus with a driver) grow to account for over 20% of the total demand in cities by 2050. This is mainly through optimised shared services, where travellers share the same vehicle with a driver for at least a part of their trip. The share of more traditional public transport (bus, rail, metro) grows modestly from 30% in 2015 to over 35% of all urban passenger-kilometres travelled by 2050. Growth in demand for shared modes and public transit is mainly due to a gradual increase in the provision of new shared mobility services that better fit the customers' needs and continued improvements in mass public transport services.

CO_2 emissions from urban travel fall by 20% in 2050 compared to 2015 in the current ambition scenario, even though total passenger-kilometres double. This is largely due to increased vehicle load factors (due to the increase of the share of optimised shared mobility services and public transport) and improved vehicle fuel economy. Average CO_2 emissions per passenger-kilometre (gCO_2/p-km) fall from around 126 g CO_2/p-km in 2015 to 50 g CO_2/p-km in 2050. The CO_2 emissions from an average car (i.e. g CO_2 per vehicle-kilometre) fall by 48% in North America, by 54% in the People's Republic of China and India and by 43% globally, in line with IEA's New Policies Scenario.

The high ambition scenario for urban passenger transport

In the high ambition scenario, policy makers implement a set of ambitious policy measures that aim to optimise the use of scarce public space and reduce negative externalities from urban transport. The uptake of electric vehicles is accelerated, following the EV30@30 scenario (IEA, 2018[4]). Transport modes are better integrated than in the current ambition scenario, resulting in a higher mode share of public transport and active transport modes (walking and cycling). More money is invested in mass public transport, and integrated policies for transport and land use result in more densely populated urban areas.

Policy makers also seek to manage car use and regulate parking more actively to incentivise more space-efficient transport, reduce congestion and decrease greenhouse gas emissions. Teleworking is encouraged, which reduces travel activity compared to the current ambition scenario. Given uncertainty around the effect of shared and autonomous mobility on overall travel activity (and hence CO_2 emissions), the high ambition scenario does not include policies that could accelerate the uptake of these potential disruptions, and thus the provision of shared modes and autonomous mobility is the same as in the current ambition scenario.

Projections based on the high ambition scenario see overall travel distance in urban areas fall in the coming decades. Urban passenger-kilometres travelled in 2050 under these assumptions are 15% lower than in the current ambition scenario. This is due to shorter travel distances in cities that are more densely populated as result of land use policies. A higher share of travel by public transport and higher use of shared modes also translate into shorter travel distances on average than compared to private vehicle use. Finally, more teleworking leads to a moderate decrease in overall travel activity.

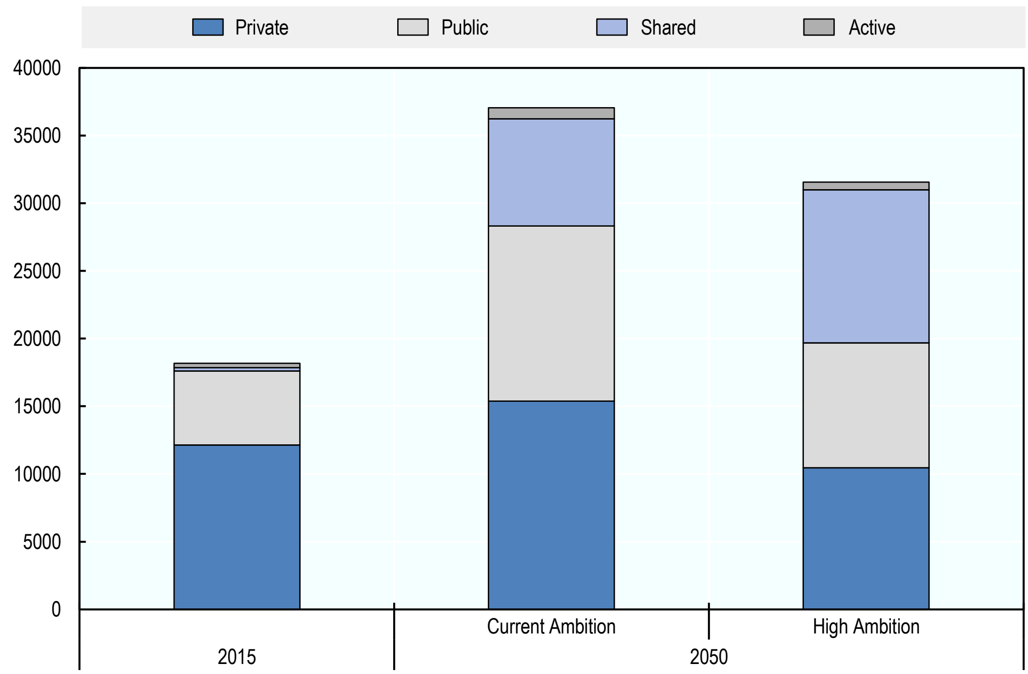
The share of private modes of all urban travel falls to 30% of the urban total passenger-kilometres by 2050, compared to around 40% in the current ambition scenario and around 70% in 2015. This is the result of more targeted policies for car use and parking, combined with strong support for integrating the different transport services. Increased average vehicle occupancy and high uptake of electric vehicles help cut CO_2 emissions further. Both of these metrics decline to around 20% of 2015 levels by 2050 in the high ambition scenario, around 70% lower than in the current ambition scenario. The average level of CO_2 emissions per passenger-kilometre drops to 17g across all world regions. By 2050, the fuel economy of an average car improves by around 75% compared to 2015 with high ambition policies.

Table 3.1. Current and high ambition scenario specifications for urban transport

Assumption	Current ambition	High ambition
Mitigation measures		
Efficiency improvements and electric vehicles	The percentage of electric vehicles in use varies across regions: e.g. for cars 1-22% by 2050 (based on (IEA, 2018[3])– NPS)	The percentage of electric vehicles in use varies across regions: e.g. for cars 42-64% by 2050 (based on (IEA, 2018[4]) - EV30@30)
Mobility as a service (MaaS)	By 2050, 20% of travellers use MaaS solutions to plan their journeys	By 2050, 50% of travellers use MaaS solutions to plan their journeys
Public transit integration and expansion	Past trends continue to 2050	Past European trends continue to 2050 for all world regions
Land-use policies to increase urban density	Depending on the region, either stable or slight urban sprawl to 2050	Depending on the region, urban densification of 5-10% to 2050
Car access restrictions	By 2050, 20% of car trips are affected by constraints (e.g. low emission zones)	By 2050, 40% of car trips are affected by constraints
Parking pricing	Depending on the region, by 2050, parking prices are 0-20% higher than the expected purchase power of travelers	Depending on the region, by 2050, parking prices are 10-40% higher than the expected purchase power of travelers
Potentially disruptive developments		
Autonomous vehicles	0-2.5% of car trips are autonomous by 2050, depending on the region	Same as current ambition scenario
Shared mobility	Past trends in the supply of shared modes continue to 2050 (50-150% of annual growth rate of shared fleet, depending on the region)	Same as current ambition scenario
Telework	Depending on the region, 2-20% of trips are affected by 2050	Depending on the region, 3-25% of trips are affected by 2050

Figure 3.2. Projected mode shares for urban mobility, 2015-50

Current and high ambition scenarios, billion passenger-kilometres



Note: Private refers to private motorised vehicles or taxis. Public refers to bus, metro, tram, and rail; Shared refers to motorised and non-motorised shared vehicles, including shared vehicle systems (i.e. free-floating or non-free-floating shared cars, bikes or other) and optimised shared mobility services (i.e. shared taxis, vans or minibuses with a driver); Active comprises travel undertaken by foot, bicycle, or other human-powered mode (where a vehicle is not publically shared).

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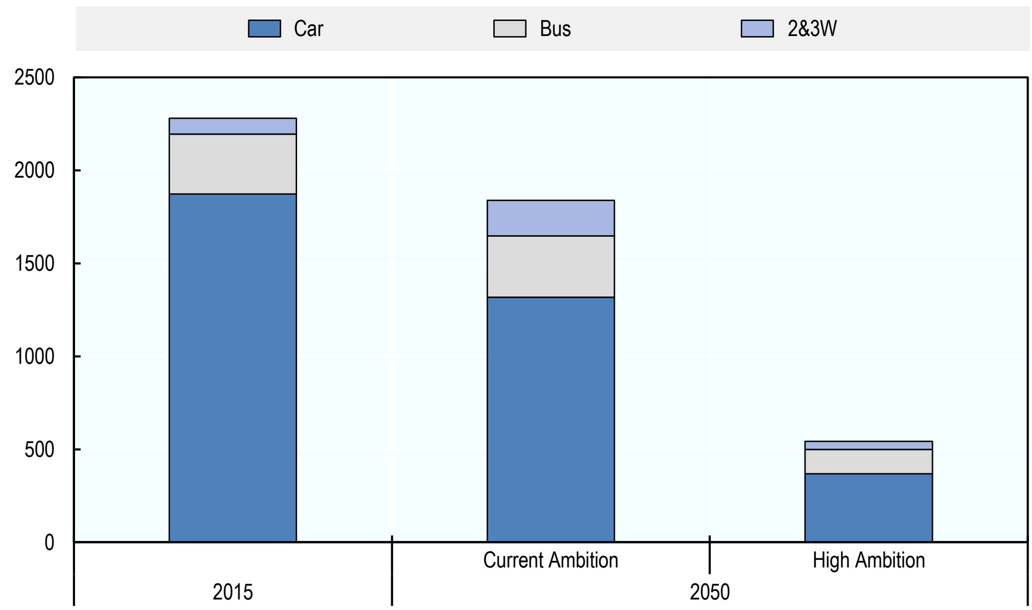
Figure 3.3. Projected CO_2 emissions by mode, 2015-50

Current and high ambition scenarios, million tonnes



Note: See Note of Figure 3.2.

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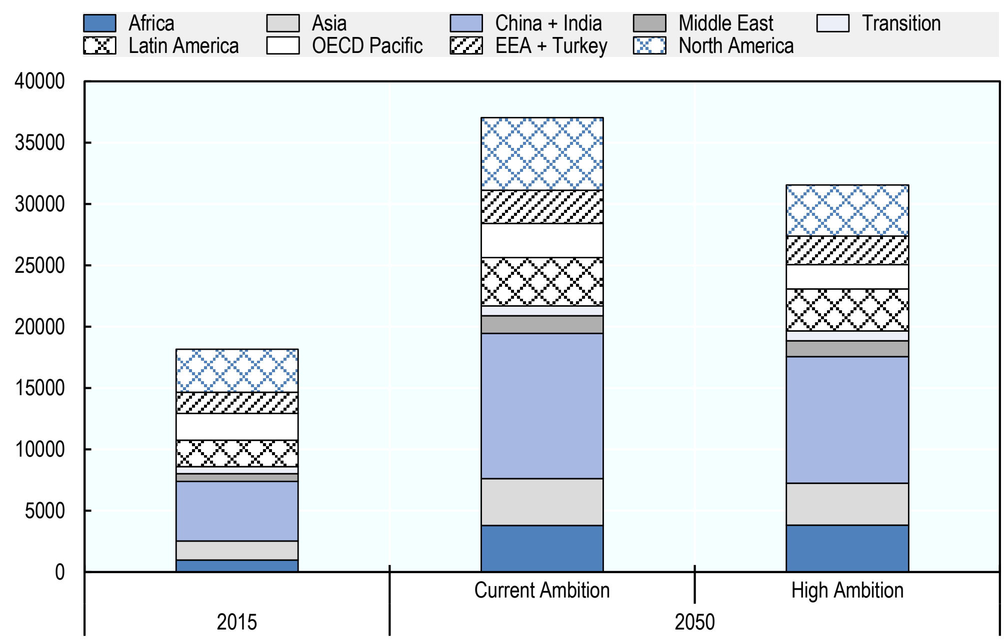
Urban mobility by region

The biggest relative increase in urban mobility demand in coming decades will occur in Africa. By 2050, Africa's urban transport will almost quadruple compared to 2015 in the current ambition scenario and the continent's share of global urban passenger-kilometres travelled will double from 5% to 10%. Other fast-developing regions such as China and India, the Middle East and other parts of Asia will see urban mobility demand more than double by 2050 (see Figure 3.4). In China and India, mobility demand in cities will increase by around 7 000 billion passenger-kilometres from 2015 to 2050 under the current ambition scenario. This is the largest absolute increase of urban mobility demand across the globe. The volume of urban travel in China and India will increase from around one quarter of total global urban passenger-kilometres in 2015 to around a third in 2050.

Even in regions where the growth in urban passenger-kilometres is expected to be lowest, the increase will still be significant: the increase for the OECD Pacific region is projected at 30% and for transition countries at 40%.[4]

Figure 3.4. Projected urban mobility shares by world region, 2015-50

Current and high ambition scenarios, billion passenger-kilometres



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Local pollutants

Urban transport is an important contributor to local air pollution, principally through the emission of oxides of nitrogen (NO_x), sulphates (SO_4) and particulate matter measuring 2.5 microns or less ($PM_{2.5}$). These pollutants contribute to severe health problems including cardiovascular and respiratory diseases and numerous cancers. The World Health Organization estimates that more than 90% of the world population lives in areas where air pollution is above the limits for healthy living (WHO, 2016[5]).

There is no necessary correlation between the contribution of urban transport activity to CO_2 levels and to local air pollution. Emissions of CO_2 are strictly proportional to fuel consumption of vehicles, while the quantity of local pollutants per unit of fuel in exhaust fumes can vary greatly. This *Transport Outlook* uses emission factors from the Roadmap model of the International Council on Clean Transportation (ICCT, 2019[6]) to estimate the emission of local pollutants resulting from the urban mobility levels of the two scenarios examined. The ICCT Roadmap includes expected improvements in vehicle efficiency standards and their probable penetration in vehicle fleets until 2050.

In the current ambition scenario, the total PM and SO_4 decrease over the coming decades, while urban transport NO_x emissions stay relatively stable up to 2050 (see Figure 3.5). However, cities in some world regions will still experience significant increased air pollution if policies do not focus on addressing them. The Middle East will see NO_x grow by 73%, SO_4 by 197% and $PM_{2.5}$ by 185%. In Africa, the projected increases are 78% for NO_x, 136% for SO_4 and 136% for $PM_{2.5}$. The rise of air pollution from transport in these regions is related to the overall growth in the size of these cities, but also to the increasing rate of motorised private transport in the respective regions. Pollutant emissions fall especially where further increases in the use of cars is limited and where vehicles are increasingly electrified, especially in the European Economic Area (EEA) and in Turkey.

The high ambition scenario demonstrates how mitigation measures could attenuate the growth of pollutants from urban mobility. The main factor that would improve the situation is the increased penetration of zero-emission vehicles compared to the current ambition scenario. Yet urban air pollution caused by transport would still increase in some cities even under the high ambition scenario. Figure 3.6 shows the difference in the urban air pollution from transport between 2050 of the high ambition scenario and the base year 2015, expressed in percent. NO_x emissions would still increase in 5% of cities around the globe. The increases of SO_4 and $PM_{2.5}$ are geographically more limited, mainly to Africa and the Middle East.

Figure 3.5. Pollutant emissions from transport by region

Current and high ambition scenarios, 1 000 tonnes of tailpipe emissions

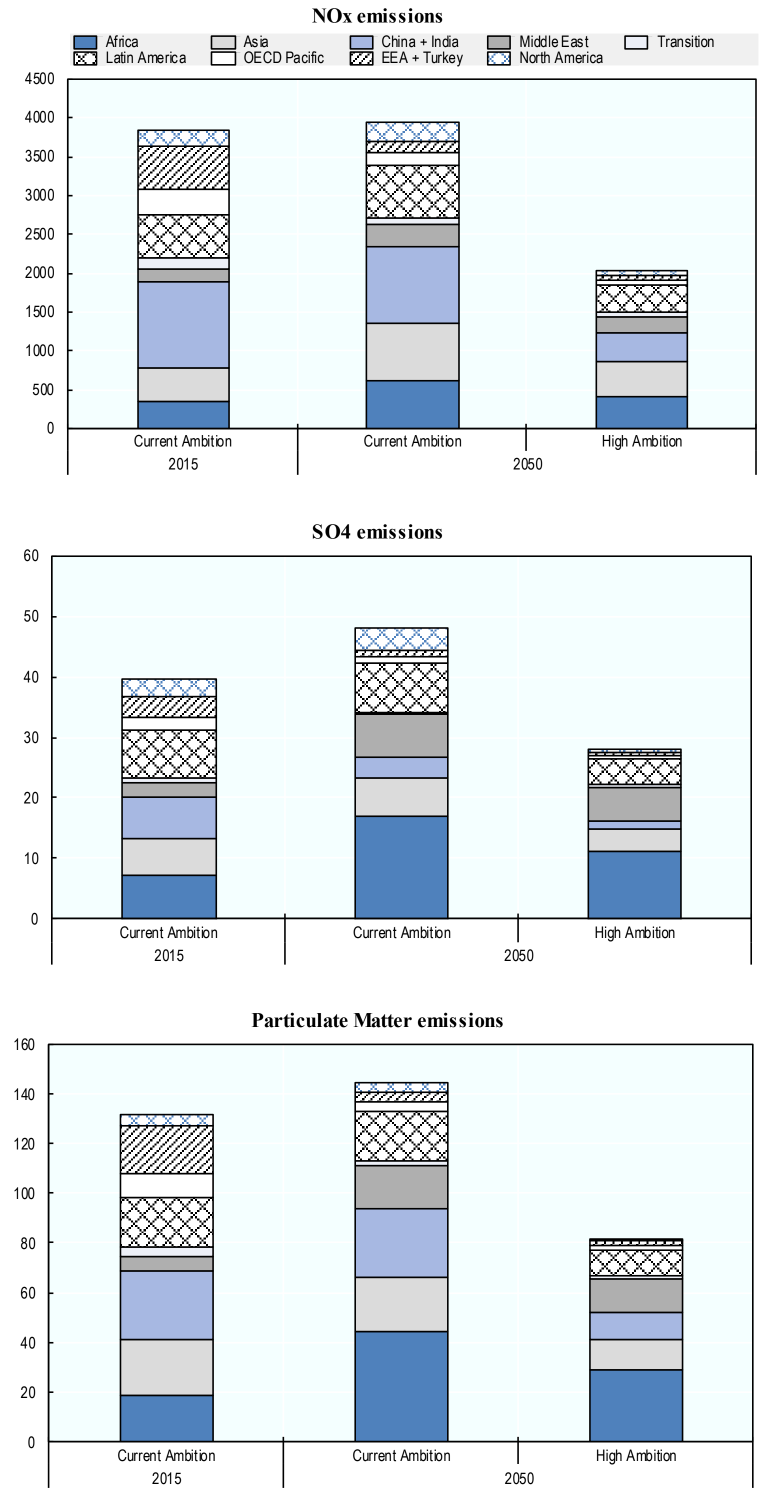

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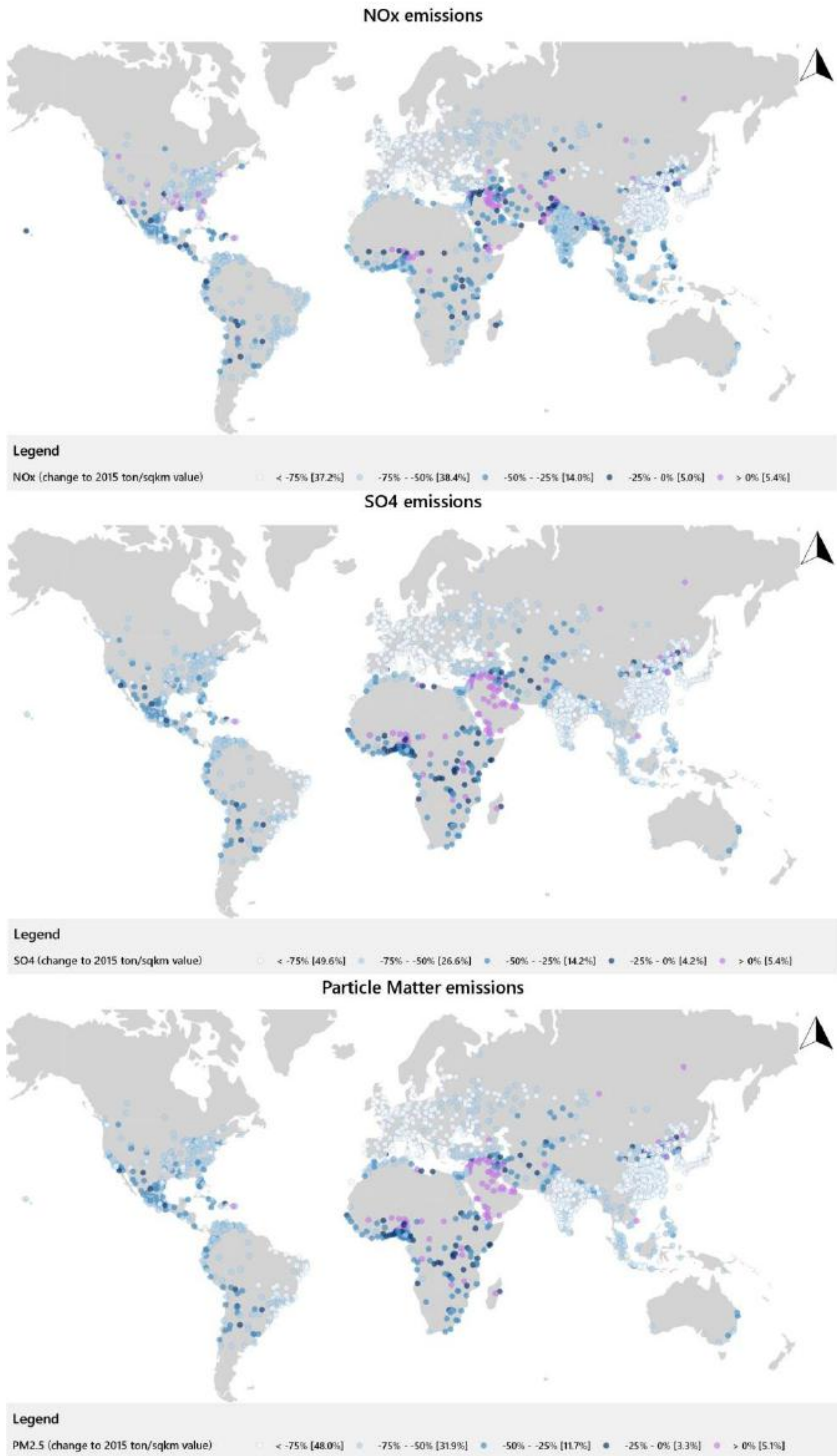
Figure 3.6. Pollutant emissions from transport

Difference between high ambition scenarios and 2015, percentages



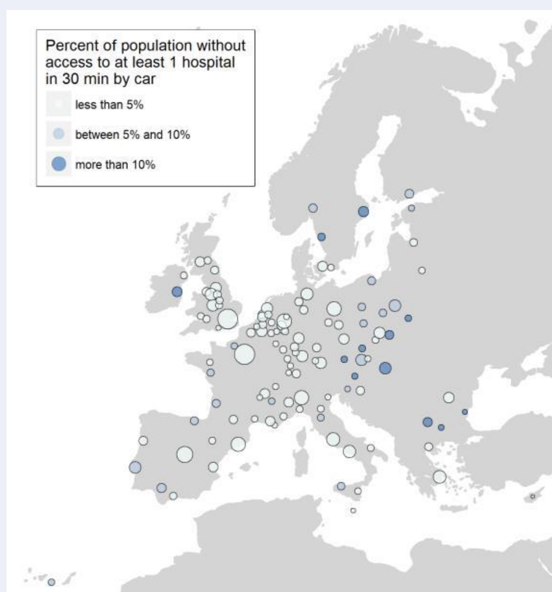
Predicting the health impacts of these scenarios is difficult. The provided estimates only account for tailpipe emissions; for example, they do not include non-exhaust emissions of PM from tyre- and brake-wear. Also, transport is of course not the only contributor to local pollutants. Several other factors, such as the topography, climate and the presence of industry enter into the equation. That said, the projections for this *Transport Outlook* show that much of this increase will occur in cities that are already suffering from air pollution today, and in which additional emissions are likely to cause even more significant health issues. Extra effort is required to develop no- or low-emission public transport, especially in medium-sized cities where investing in rail transport may not be an option.

Box 3.2. The International Transport Forum urban access framework

Accessibility is a growing policy priority. Improving the ease with which citizens can reach goods, services or activities is increasingly recognised as the ultimate goal of transport policies, and more relevant than enhancing speed or reducing congestion. However, metrics that capture accessibility are rarely used in decision making.

Figure 3.7. Urban population in Europe without access to a hospital within 30 minutes by car

Percentages



Note: Circle size corresponds to total population.

The ITF urban access framework provides a set of indicators, computing methods and databases that make possible large-scale accessibility studies (ITF, 2017[2]) .It allows for an assessment of accessibility with regard to a number of different destinations types, such as jobs, schools and hospitals. The framework also allows for analyses that isolate the influence of speed and proximity on accessibility.

In a forthcoming ITF report, Benchmarking Accessibility in Cities: Measuring the impact of proximity and transport performance (ITF, forthcoming[7]), the framework has been applied to all European cities of more than 500 000 inhabitants. The analysis showed that average accessibility to goods and services in these cities is high, but that this average value masks important disparities. For example, more than 97% of the population in the cities examined has access to a hospital in less than 30 minutes by car.

Yet in many Eastern European cities (e.g. Sofia in Bulgaria, Budapest in Hungary, or Lublin in Poland) the share is around 90%. It falls to less than 70% when considering only the residents of commuting zones. In these areas, a significant share of the urban population would need to travel for more than 30 minutes to reach a hospital. This has obvious implications for policy, considering that access to quality essential health services is an objective under the United Nations Sustainable Development Goals (SDG).

The ITF urban access framework was developed as part of a project funded by the European Commission and carried out in collaboration with the OECD's Centre for Entrepreneurship, SMEs, Regions and Cities.

Disruption through telework

Telework and other forms of remote presence can improve accessibility, increase productivity and enhance competitiveness. Working remotely can create jobs, foster smart growth while adding to the overall well-being of employees. In terms of impact on the transport sector, telework helps to reduce the number of commuting work trips, thus alleviating traffic on transport networks during the busiest periods. To the extent it can reduce motorised trips, teleworking reduces CO_2 emissions. Encouraging teleworking thus has a potential role in travel demand management strategies that aim to decarbonise transport.

Telework is broadly defined as carrying out work at a location that is remote from the employer's site while staying connected to the office via network technologies. Telework can also encompass flexible working arrangements that shift commuting activities to off-peak hours. In the context of this analysis, however, teleworking is considered as working arrangements that reduce the total number of trips to the office.[5]

The concept of teleworking was first proposed as an official arrangement in the United States in 1973 as a reaction to high oil prices and in response to the Clean Air Act of 1970. Telework was initially expected to revolutionise the workplace and eventually be adopted by a significant portion of the workforce. Yet teleworking was still the exception a quarter century later, with only 7% of workers working from home at least once a week in the United States in 1997 (ILO-Eurofound, 2017[8]). In the European Union (EU), only 5% of the employed population were working remotely at least a quarter of their working hours in 2000 (Eurofound, 2010[9]).

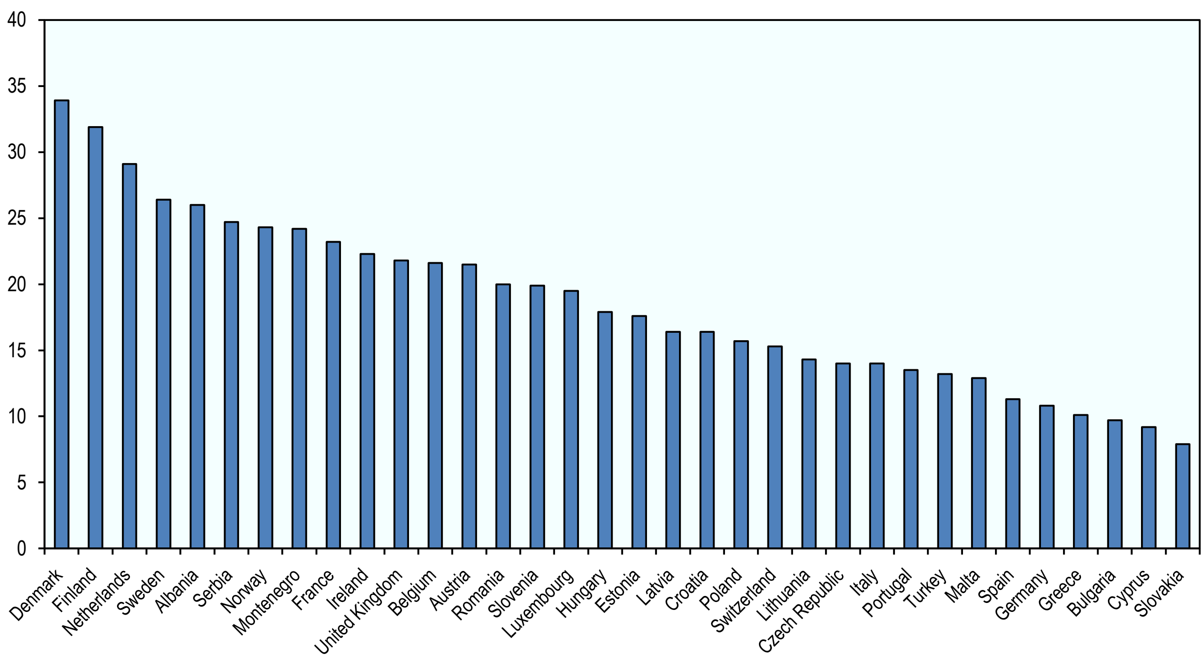
The prevalence of telework has since increased, largely due to the rise of the internet and mobile technology and the increasing social acceptability among both employers and employees. In 2010, nearly 10% of the employed population in the United States worked remotely at least once a week, and teleworking constitutes the fastest-growing commuting pattern. Growth in telework activity has been highest among urban populations (Mateyka, Rapino and Landivar, 2012[10]).

The lack of a harmonised definition and data collection practices regarding teleworking make cross-country comparisons somewhat difficult. Nevertheless it is possible to identify some general patterns and trends from the available data.

First, large variations in the prevalence of teleworking exist. Telework shares worldwide range from 2% to 40%, depending on the region and the sector (Gschwind et al., 2017[11]). In Europe, teleworking rates are highest in Denmark, Finland, and the Netherlands, where approximately 34%, 32%, and 29% of the population report teleworking. Across all countries, the prevalence of teleworking tends to be highest among highly-skilled employees such as managers, professionals, technicians (ILO-Eurofound, 2017[8]). Figure 3.8 reports the teleworking rates within the EU.

Figure 3.8. Workforce working at home several times per month, 2015

Percentages



Source: Eurofound (2017[8])

StatLink http://dx.doi.org/10.1787/888933972620

Relatively low rates of teleworking are found in southern Europe, with 10.1% teleworkers in Greece, 11.3% in Spain and 14% in Italy (ILO-Eurofound, 2017[8]). Germany also has a comparatively low proportion of teleworkers, with only 10.8% of the employed population working from home several times a month. Self-reports from a global survey of knowledge workers in the Asia-Pacific and Africa-Middle East regions suggest low rates of teleworking relative to most high-income countries (PGi, 2015[12]).[6]

Table 3.2. Teleworking rates in selected non-EU countries

Country	Group	Year	Teleworking rate (%)
Argentina	All workers	2011	2.0
India	Workers in non-agricultural organised sector	2015	19
Japan	All workers	2010	16.5
United States	All workers	2015	24.1
Canada	All workers	2015	12.8

Note: In India, the non-agricultural organised sector represents approximately 15% of all workers in the country ILO-Eurofound, (2017[8]). As a result, the estimated teleworking rate among all workers in India is likely to be lower than the figure reported.
Source: National reports compiled in Eurofound (2017[8]), unless otherwise noted; Data for Japan obtained from the Ministry of Internal Affairs and Communications (2011[13]); Data for the U.S. Bureau of Labor Statistics (2016[14]) ; Data for Canada obtained from Statistics Canada (2016[15]); Data for Australia obtained from MIAESR (2013[16]).

What drives the decision to telework?

Teleworking requires a compatible assignment, i.e. tasks that can be executed using remote technologies. It also requires the availability of the relevant equipment, the literacy to operate it and an adequate working environment at the remote location (with internet access and a physical space to work). Finally, a formal or informal agreement between employee and employer regarding teleworking activity is essential.

A number of additional factors influence employees' propensity to telework and the frequency with which they operate remotely. Sociodemographic characteristics, attitudes, and geographical accessibility are further determinants of the propensity to telework. Women, workers on high incomes and employees with advanced education levels tend to telework more than other groups; another one is employees in households with children telework (Walls, Safirova and Jiang, 2006[17]; Singh et al., 2013[18]; Loo and Wang, 2018[19]).

The propensity to telework correlates positively and consistently with the length of commutes (Helminen and Ristimäki, 2007[20]; Melo and de Abreu e Silva, 2017[21]). A causal relationship is not clear, however. Employees who have longer commutes may be more likely to telework, but equally the opportunity to telework might lead employees to choose their residence farther away from their place of work (Melo and de Abreu e Silva, 2017[21]). In reality, this association is likely to reflect a combination of these two effects.

Teleworking is subject to regulations set by governments. It is also informed by cultural norms. National differences in the legal framework and societal attitudes partly explain the wide range in teleworking rates across countries. A culture of "presenteeism" – the pressure to be physically present at work – can constitute a formidable disincentive to telework (Wilton and Scott, 2011[22]).

The attitudes of management play an important role in the shaping of acceptance of teleworking within an organisation (Haddad and Chatterjee, 2009[23]; Mayo et al., 2016[24]). Managers may be reticent to support teleworking for fear of a detrimental impact on employee engagement and company culture. They may also be averse to losing direct managerial control over the time of teleworking employees. This cautious attitude characterises managerial perspectives on telework in China and India, for instance – countries where the potential benefits from higher level of teleworking are quite significant. Some analyses suggest that these concerns are, on average, unfounded (Gajendran and Harrison, 2007[25]).

A recent study of Chinese workers also found that teleworking increased productivity and thus constitutes a profitable management strategy (Bloom et al., 2015[26]). Evidence also suggests that increasing the visibility of public sector involvement in teleworking can have a positive effect on telework activity (Mokhtarian, 1991[27]). A number of governments around the world have introduced legislation or resolutions aiming to make teleworking more feasible for their citizens, including China, the Czech Republic, Colombia, Japan, and Romania.

A specific aspect in this context is the emergence of the so-called gig economy: independent workers who string together short-term contracts that they fulfil via offline or online activities. Approximately 31% of US workers are self-employed in the gig economy, most of them in addition to other forms of employment, according to US Federal Reserve estimates. About half of these (16%) are involved in on-line gig work such as fulfilling task-based contracts remotely.[7] If the latter group increasingly substitutes full-time office jobs, telepresence could reach levels that reduce the amount of work-related travel. Linked to this development is the rise in off-site office spaces such as WeWork that cater to gig-workers. Few statistics exist on the size and nature of the gig economy, but such work arrangements may in the future have a growing impact on travel demand, especially where they involve tasks being completed remotely.

How does teleworking change travel behaviour?

The main impact of teleworking on transport is to reduce travel demand during peak hours. This alleviates congestion and reduces air pollution, helps to avoid traffic crashes and eases pressure on public transport infrastructure.[8]

Empirical evidence indicates that teleworking can reduce traffic volume by as much as 2.7% (Choo, Mokhtarian and Salomon, 2005[28]; O'Keefe et al., 2016[29]; Giovanis, 2018[30]). The magnitude of any impact of teleworking is highly dependent on the context. The degree to which teleworking reduces emissions, for instance, depends on factors such as commuting, climate, and induced energy use patterns, as well as the characteristics of the office and remote/home space, as well as the dominant electricity mix (Kitou and Horvath, 2003[31]). In areas with high levels of public transport use, for example, CO_2 reductions from teleworking will likely be lower compared to areas where vehicles with internal combustion engines are the dominant choice for commuting.

The net impacts of telework can be ambiguous. This is especially the case when its indirect, often behavioural impacts are taken into account. Evidence indicates that teleworking may go along with an increase in the number of trips that are not work-related (Kitou and Horvath, 2003[31]; Glogger, Zängler and Karg, 2008[32]; Falch, 2012[33]; Zhu et al., 2018[34]). Other studies show that telework is positively associated with increased frequency of non-urban trips and increased household energy use (Kitou and Horvath, 2003[31]).

Such indirect effects of teleworking taken together can create rebound effects, i.e. actually increase total travel volume and limit any overall positive impact of teleworking on transport demand and emissions e.g. (Melo and de Abreu e Silva, 2017[21]). Telework could even contribute to more urban sprawl, to the extent that it prompts workers to locate their homes farther away from the office (Nilles, 1991[35]). Evidence regarding the impacts of teleworking in the literature is also highly influenced by the type and intensity of teleworking activity considered (e.g. one day per week vs. three days per week), and as such, should also be taken into account when reviewing the empirical evidence for its impacts (Ben-Elia, Lyons and Mokhtarian, 2018[36]).[9]

Attitudes towards teleworking are increasingly positive, according to survey results. More than 50% of teleworkers polled in all regions said they would like to work remotely more often (PGi, 2015[12]). At the same time, the further evolution of various technologies will make it easier to telework and could thus stimulate the mainstreaming of telework in significant ways.

On the other hand, improved public transport could reduce the appeal of teleworking by shortening commutes and making them more agreeable. Greater fuel efficiency of internal combustion engines and advances with electric vehicles (such as better charging infrastructure, greater range of cars) could also reduce cost-related incentives to telework. Although the value of teleworking in terms of reducing CO_2 would decrease as the transport sector decarbonises, cities would continue to benefit from reduced congestion.

Simulation results

The ITF urban passenger model was used to run a scenario simulating the impact of increased telework activity on transport demand. The effects of teleworking are estimated according to the impacts documented in the available literature. They are assessed in comparison to current ambition scenario, in which teleworking takes up only at a very moderate pace. In the scenarios that simulate a disruptive development pathway for transport, telework affects between 3% and 30% of urban trips by 2050, depending on the region. The simulation results indicate that the increased uptake of teleworking leads to a decrease in global urban passenger-kilometres and related CO_2 emissions of around 2% compared to the current ambition scenario in 2050, indicating that the rebound effect does not lead to an overall increase in transport demand.

Massive shared mobility

The rise of the sharing economy is one of the most remarkable disruptions in recent years, both inside and outside of the transport sector. In the sharing economy, people seek to maximise the utility of under-used assets by linking supply and demand directly, usually via an online platform. The sharing economy leverages ubiquitous digitalisation for better service, more efficiency and new business models that have the potential to drastically change conventional transport systems.

A wide range of shared and quasi-shared mobility services are already available today. They include round-trip or free-floating carsharing, private short-term car rentals managed through app-based platforms, ridesourcing services for single-occupancy or shared trips, on-demand mini-bus services with flexible routes, peer-to-peer ride-sharing services, as well as bicycle and micromobility sharing (see Table 3.3).

Table 3.3. The evolving urban passenger mobility landscape

Travel modes	Mobility applications	Service models	Operational models	Business models
Self-owned car/bike/other	Business-to-consumer sharing apps	Ownership	Station-based roundtrip	Business-to-consumer services
Taxi	Mobility tracker apps	Membership-based service models	Station-based one-way	Government-to-consumer services
Rental car	Peer-to-peer sharing apps	Non-membership service models	Free-floating one-way	Business-to-government services
Public transport	Public transport apps	Peer-to-peer service models		Business-to-business services
Bikesharing	Real-time information apps	For-hire service models		Peer-to-peer mobility marketplace
Carsharing	Ridesourcing apps	Public transport services		Fractional ownership
Microtransit	Taxi e-hail apps			
Rickshaws	Trip aggregator apps			
Personal vehicle sharing				
Ride-sharing				
Ridesourcing				
Micromobility sharing				
Scooter sharing				
Shuttles				

Note: Bikesharing refers to on-demand access to bicycles at a variety of docked or free-floating pick-up and drop-off locations for one-way (point-to-point) or roundtrip travel; Carsharing offers users access to vehicles by joining an organisation that provides and maintains a fleet of cars and/or light trucks; Microtransit refers to privately or publicly operated, technology-enabled transit service that typically uses multi-passenger/pooled shuttles or vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing; Rickshaws refer to for-hire services in which a driver transports users in a motorised or human-powered light vehicle containing three or more wheels and a passenger compartment; Personal vehicle sharing refers to the sharing of privately-owned vehicles, where companies broker transactions between vehicle hosts and guests; Ride-sharing refers to the formal or informal sharing of rides between drivers and passengers with similar origin-destination pairings (e.g. carpooling and vanpooling); Ridesourcing refers to prearranged and on-demand paid transportation services in which drivers and passengers connect via digital applications; Micromobility sharing provides individuals paid access to a fleet of (mostly) electric micromobility devices such as push scooters deployed and maintained by an operator; Scooter sharing provides individuals paid access to a fleet of moped/scooters deployed and maintained by an operator; Shuttles refers to shared vehicles (typically vans or busses) that connect passengers from a common origin or destination to public transit, retail, hospitality, or employment centres.
Source: Adapted from SAE (2018[37]).

These services exploit current technologies to expand the spectrum of mobility options available to individuals. Propelled by the development of Mobility as a Service (MaaS) platforms, they are also becoming more integrated with standard public transport. This is the case especially when shared mobility can feed efficient, high-capacity public transit services. At the heart of this trend is the continued growth and infiltration of digital technology in all aspects of the economy and human lives.

Why do people choose shared mobility?

Understanding the differences in land use patterns, transport supply and culture is important to appreciate how travel patterns may change with the massive adoption of shared mobility services and the replacement of private mobility by them. The layout of land use in cities determines the need for motorised mobility and average travel distances. Density and land use mixtures but also the commuting structure of a metropolitan area may set the city mobility profile. Another key element is transport infrastructure and public transport services provision.

A variety of elements shape the mobility and accessibility ecosystems in cities, and these ecosystems in turn influence car ownership rates and resulting transport mode choices. A higher density and smaller size can lead to higher shares of non-motorised travel in a city, but poor public transport and urban sprawl can also create conditions that encourage car-oriented mobility. The significant presence of bus networks in some cities indicates that some travellers do currently use this alternative over private vehicles, due to either financial constraints or personal choices regarding car ownership. In this way, a number of city characteristics (e.g. mode shares, the quality and extent of public transit services, socio-economic characteristics) are important in assessing the comparative advantage of shared mobility relative to existing transport options. For example, focus group studies carried out by the ITF show that citizens in Finland's capital Helsinki are specifically looking for services that connect different outer areas of the city with each other (ITF, 2017[38]). In the Irish capital, Dublin, shared services could be useful as feeder services to public transport for residents in suburban areas (ITF, 2018[39]).

The choice of ridesourcing is often linked to parking prices and availability and a desire to avoid drink-driving. In the United States, the choice of ridesourcing versus public transport, cycling or walking is often linked to greater convenience and comfort. The use of ridesourcing services tends to peak in the morning and (even more so) in the (late) evening. These peaks coincide with increased traffic and therefore contribute further to already existing congestion. Trust, cost and ease of use (encompassing payment, waiting time, software interface, etc.) are also factors that conceivably influence the uptake of various shared mobility options. By building trust and enhancing the ease of use, mobile apps and MaaS platforms play a fundamental role in promoting the uptake of shared mobility.

What are the implications of shared mobility use for urban transport?

The rise of shared mobility services has led to a debate in cities around the world about how they should be regulated and how cities should interact with the players (e.g. taxis). The discussion also revolves around safety impacts of shared mobility services and their influence on travel behaviour. Some studies suggest that shared services help reduce vehicle ownership and increase use of public transit. Others find that the early adopters of these services are unsatisfied public transport users who add traffic to already congested streets by switching to shared vehicles. Furthermore, the short- and medium-term effects of shared mobility on mode choice and car ownership may not compensate for the possible long-term effect of greater urban sprawl if counteracting policies are not put in place.

A number of studies have explored the impact of shared mobility penetration on the market for urban mobility. Many focus on the observed effects of transport network companies (TNCs) and on environmental performance indicators (Shaheen et al., 2017[40]). Others are more prospective in nature, either using simulation-based experiments to assess the future adoption of shared mobility solutions at a large scale (Ciari, Schuessler and Axhausen, 2013[41]; Spieser et al., 2014[42]; Liu et al., 2017[43]; Zachariah et al., 2014[44]; Fagnant and Kockelman, 2016[45]), or by offering expert assessment of aggregate impacts of massive shared mobility adoption in different urban contexts (Shaheen et al., 2015[46]; Clewlow and Mishra, 2017[47]; Ronald et al., 2017[48]; Fulton, 2018[49]).

Most studies have examined the observed impacts of carsharing, ride-sharing and new TNC services on mode choice, changes in total motorised mobility (e.g. vehicle-kilometres travelled) and changes in car ownership. Some positive effects have been noted, such as modest shifts away from private car use, lower car ownership rates and increased public transport use (Shaheen et al., 2017[40]). Yet a significant share of users switch to shared mobility from public transport or active transport modes for some of their medium-distance trips. Additionally, the greater accessibility engendered by shared mobility services may aggravate urban sprawl if leads residents and business owners to locate farther away from city centres. Shared mobility systems have also been shown to lead to additional travel in some cities with large vehicle fleets (Bliss, 2017[50]; Bliss, 2017[51]). In these cases, policies may need to be put in place to ensure that shared mobility provides benefit (Karim, 2017[52]).

The impact of shared mobility on total vehicle-kilometres travelled, congestion, and emissions depends on average occupancy rates and the efficiency of the vehicle fleets in operation (ITF, 2016[53]). If larger shared vehicles are used, producing average occupancy rates greater than six passengers, the benefits of shared mobility are much greater (Alonso-Mora et al., 2017[54]; ITF, 2017[55]).

A number of simulation-based studies on the potential impacts of shared mobility services with high occupancy rates have been carried out by the ITF for a number of different cities including Lisbon and its metropolitan area in Portugal (ITF, 2015[56]; ITF, 2016[53]; ITF, 2017[55]), the metropolitan area of Helsinki in Finland (ITF, 2017[38]), the metropolitan area of Auckland in New Zealand (ITF, 2017[57]), the Greater Dublin Area in Ireland (ITF, 2018[39]) and the metropolitan area of Lyon, France (ITF, forthcoming[58]). These studies explored the impact of different levels of shared mobility uptake that displaces private vehicle trips and low-frequency bus services. Overall, the results show that the extent of the positive impacts of shared mobility in urban centres depends in large part on the characteristics of the cities studied, as well as on the specific aspects of the design of the shared mobility systems considered.

The results also indicate that densely populated cities that are well-connected by public transport are likely to be more fertile ground for the development of shared mobility solutions than cities characterised by sprawl and lower public transport connectivity. However, less dense cities arguably stand to gain significantly from affordable shared mobility services that feed public transport lines. In a scenario in which all private car use is replaced by the massive uptake of shared mobility in conjunction with existing public transport systems, vehicle-kilometres and CO_2 emissions are reduced by 30% to 60% compared to current mobility patterns. Lower uptake of shared mobility, such as that which replaces 20% of private car use in some cases reduces vehicle-kilometres by more than 10%. Such relatively modest adoption levels seem plausible, based on feedback received from potential users participating in stated preference surveys and focus groups in some of the cities studied.

Overall, the existing evidence indicates that current, decentralised shared mobility providers do not significantly reduce total vehicle-kilometres travelled in cities. Indeed, the current trend in shared mobility has, by and large, only changed the face of personal transport and even reduced public transit ridership (Graehler, Mucci and Erhardt, 2018[59]). Shared mobility solutions have three observed benefits: Firstly, they can encourage the use of more efficient vehicle technologies. Secondly, they can reduce the fleet of private cars that consume urban space when parked. Finally, shared mobility services can also provide inter-urban transport. In some markets, these solutions by operators such as France's BlaBla Car make up 5% of interurban travel. However, shared inter-urban trips are unlikely to replace private trips entirely; more likely is that their share will stay below 50% (Shaheen, Stocker and Mundler, 2017[60]).

How shared mobility continues to develop will depend on regulatory frameworks and on its relationship with public transport. Existing public transport operators may see shared mobility as a potential substitute for their own services, rather than a complement, although this is changing rapidly. Another challenge from the introduction of shared mobility is a potential fall in mobility costs and a related increase in urban accessibility. Urban and regional planning will need to address such effects of shared mobility in order to avoid urban sprawl. Policies that favour densification and extensive coordination with public transport networks are paramount (ITF, 2017[55]).

The significant potential gains of shared mobility will not materialise unless appropriate regulations are in place regarding empty trips, fare structure, integration with public transport and also the design of the dispatch algorithm that allocates rides to riders. Failing these, increased congestion and additional CO_2 emissions, not less, may be the outcome (Shaheen et al., 2015[61]; Santi and Ratti, 2017[62]).). The interaction of shared mobility with electric mobility and self-driving technologies can even potentiate the penetration of services at lower costs and accelerate the decrease in car ownership rates (Fulton, 2018[49]).

Box 3.3. Mobility as a Service

Urban mobility is typically provided by a patchwork of poorly-optimised and disconnected service providers operating with little coordination on both public and private infrastructure. Urban mobility ecosystems are evolving with respect to new forms of transport modes. But the ways in which users' access and pay for mobility are also changing, as are the service models, operational approaches and business cases models that deliver it (Table 3.3).

The large-scale diffusion of ubiquitous sensing devices, portable, remote and edge computing capabilities, IT infrastructure, new data treatment and analysis protocols, data-fed algorithms and wide-spread, fast, reliable and robust communication networks all lead to an unprecedented revolution in the way in which transport stakeholders can optimise multiple and converging goals and outcomes. At its core, the concept of MaaS supports the digital joining-up of different transport, information and payment services into a smooth and reliable customer-facing experience.

Digitalisation holds great promise to break independent silos of separately regulated services in the transport sector and deliver mobility not as a discrete transaction based on a single operator or mode but as a continuum of services that reliably allow travellers to meet their access needs and desires – in other words, Mobility as a Service (MaaS). Globally, non-OECD regions account for the dominant share of these new services, with China accounting for 68% of the global on-demand mobility market (with bikesharing slightly dominating ridesourcing in that country). A main driver for the uptake of new mobility services and MaaS will be the enabling legislation and standardised data protocols that ensure seamless linking of service operators, trips, payment options and regulatory reporting (Yanocha, 2018[63]).

The potential impacts of MaaS depend on the business models that are embedded into MaaS offers, as well as the policies that public authorities put in place (or not) to influence the way in which people modify their behaviour (or not) in response to the new offer. Overall, transport-related impacts are also likely to evolve in intensity and at different levels of MaaS penetration and uptake with transitional effects potentially higher than at advanced adoption levels. Potential impacts could be seen on congestion, energy use, CO_2 and traditional pollutant emissions, safety/health, and land use/real-estate market effects.

Insofar as MaaS systems facilitate the adoption of shared mobility services, they have had significant impacts on urban transport systems and will continue to do so. There is common ground among existing studies that the early uptake of ridesourcing services leads to modest substitution effects for car travel with more riders coming from public transport, walking and cycling. This finding is, however, variable between and within urban areas and is likely linked to the quality and frequency of existing public transport services and lack of safe cycling environments. Car-trip substitution effects appear to be greater in medium-sized cities and peripheral areas. The role of centralised dispatch in reducing or eliminating these impacts has been demonstrated in a series of modelling studies, although such a system has not yet been commercially deployed (ITF, 2015[56]; ITF, 2016[53]; ITF, 2017[38]; ITF, 2017[57]; ITF, 2017[55]). Other evidence suggests that carsharing households tend to own fewer cars than other like households, use public transport more often, and live in urban areas where alternatives to car travel exist (Shaheen et al., 2017[40]).

The impact of other forms of shared mobility has not been studied as extensively. Bikesharing and micromobility-sharing may lead to a switch from certain short-distance car trips in some contexts, especially where car use dominates. Where high-quality and cost-effective public transport is available, bikesharing and micromobility-sharing can serve as feeders to public transport, but often replacing walking. Where public transport is infrequent or of low quality, these modes may substitute for public transport.

These early findings may evolve – especially in an environment where many of these services are actively linked to provide low-latency, affordable, convenient and highly reliable trips. They may also be influenced by public policies in support of public transport use and active mobility.

Simulation results

The impact of massive shared mobility will heavily depend on the regulatory framework that accompanies it. As such, two scenarios were developed and tested:

In a first scenario, shared modes develop at twice the speed of past trends and the regulatory framework is loose. This leads to the increased uptake of shared vehicle systems, such as shared cars or bikes that are often used by single individuals. This encourages low vehicle occupancy rates and does not incentivise the use of public transport. To the contrary, such shared vehicle systems encourage public transport users to switch to individual means of transport. The use of private cars may decrease, but low occupancy rates of shared vehicles would not lead to a drop in overall vehicle-kilometres and the associated externalities.

In a second scenario, shared modes also develop at twice the speed of past trends, but strong regulations ensure that shared modes are optimised through supporting MaaS solutions. These encourage the use of shared mobility as feeder services for more traditional public transport systems, such as bus or rail systems. Vehicles such as minibuses or vans with drivers operate on fixed routes with fixes schedules, feeding higher capacity public transport services. They run only a very limited amount of empty vehicle-kilometres. In this scenario, people would give up the use of their private car to opt for such more efficient transport options, defined by high vehicle occupancy rates.Table 3.4 summarises the simulation results for both scenarios in comparison to the current ambition scenario (where shared modes develop more moderately, i.e. in line with past trends). Where an increased uptake of shared mobility modes is accompanied by loose regulations, vehicle-kilometres would lead to an increase of 6% by 2050. Shared vehicle systems (such as shared cars or bikes) would take mode share from two- and three-wheelers. A lack of integration of conventional public transport with other modes would result in an increase in private car use. As a result, transport CO_2 emissions increase by 18% by 2050 compared to the current ambition scenario.

Table 3.4. Projected impact of two shared mobility scenarios

Percentage change compared to current ambition scenario

Shared mobility scenario	Passenger-kilometres		Vehicle-kilometres		CO_2 emissions	
	2030	2050	2030	2050	2030	2050
Loose regulation (Further uptake of shared mobility dominated by traditional shared modes with low occupancy rates)	6	5	5	6	15	18
Strong regulation (Increased uptake of optimised shared services with high occupancy rates, supported by Mobility as a Service solutions]	1	-4	-24	-51	-3	-34

On the other hand, in a scenario where an accelerated uptake of shared modes is accompanied by strong regulation, the increased shared mobility demand is met by optimised shared mobility services that rely on MaaS solutions and are well-integrated with public transport. This leads to significant reductions in vehicle-kilometres and hence CO_2 emissions. Total vehicle-kilometres could be reduced by more than 50% thanks to high vehicle occupancy rates and a decrease in the use of private cars, resulting in CO_2 reductions of more than 30% by 2050 compared to the current ambition scenario.

Autonomous vehicles

Automated driving systems that either assist or replace humans in the driving task are rapidly being designed, tested and, in many cases, deployed in pilots around the world.[10] Vehicle automation can be partial, when the automated system of the vehicle can conduct some parts of the driving tasks. It can also be full, when the vehicle can perform all driving tasks under all conditions (geographic area, roadway type, traffic, weather, events/incidents) that a human driver could. In this latter case, the vehicle is said to be autonomous.

Some low-level and context-specific automation functions such as self-parking, lane-keeping and automated traffic jam driving are already deployed in commercial vehicles, both passenger and freight. All major automotive original equipment manufacturers (OEM) are working on integrating higher and higher levels of automation into their products.

Though there are clear industrial policy and market leadership outcomes with the deployment of successful automation technologies, much of the stated motivation for introducing automation is related to the potential road safety benefits this might deliver. The safety performance of automated vehicles, especially in relation to human-driving will both drive and condition its uptake.

The potential for automated vehicles to remove common and pernicious human errors and misjudgements from the driving task is significant (Fagnant and Kockelman, 2015[64]; Anderson et al., 2016[65]). However, it is reductionist to believe that human error has been properly identified as a contributory factor by those responsible for post-crash forensic investigation, or that all crashes involving human error could have been otherwise avoided by addressing that error.

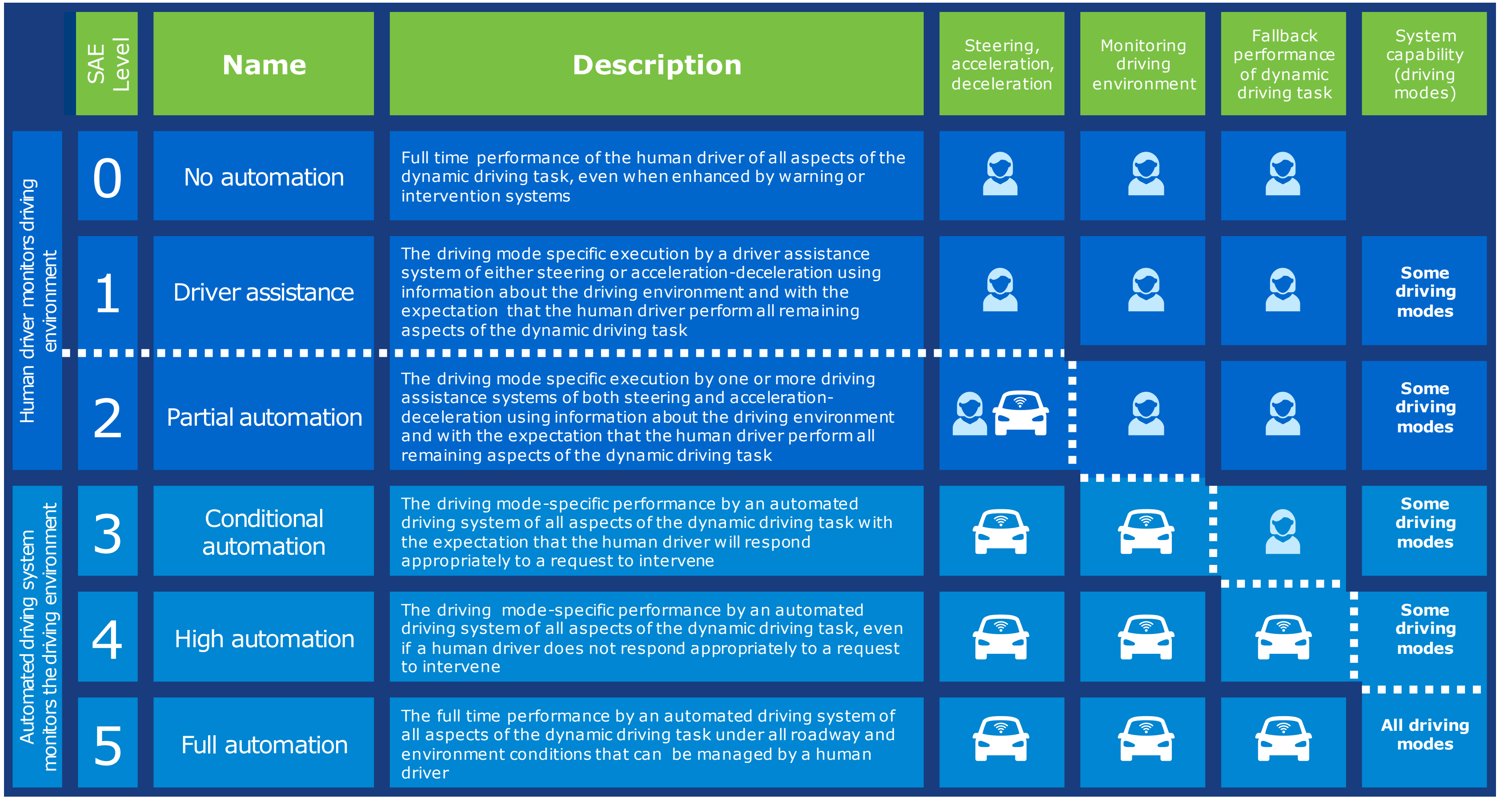
A second aspect to consider when assessing the scope for automation to improve safety outcomes by removing "human errors" in crash causation is that it does not follow that all crashes attributed to human error could have been reasonably avoided by drivers (Noy, Shinar and Horrey, 2018[66]). How much automation will improve road safety ultimately depends on how safely automated driving systems can carry out the parts of the driving task they are assigned. The technical skill with which these systems are able to handle the driver task without errors, glitches or unintended outcomes will matter here.

When considering the impacts of vehicle automation, it is important to bear in mind that not all automated systems share, or are targeting, the same performance. The capabilities of these systems vary from simply assisting drivers in certain contexts and in limited capacities to fully replacing the human driver in specific contexts. The former form the basis of a number of technologies already included in commercially available cars and trucks (e.g. lane assist, self-parking functions, limited autopilot function) whereas the latter only comprise vehicles that are being tested in various trials.

Figure 3.9 sets out the five levels of automated vehicle performance as defined by the International Society of Automotive Engineers (SAE, 2018). It categorises vehicle automation functions according to the level and scope of driving task responsibilities allocated to the human driver versus the automated system – or to both in some instances. A core issue with regards to safety is how well the handover from automated systems to human drivers occurs at SAE levels 2 and 3 when the system cannot interpret its environment satisfactorily. Machine-to-human handovers also are triggered at SAE level 4 when the driving context changes to one that is beyond the capabilities of the automated system. The SAE levels are useful in developing a complete taxonomy of automated driving system capabilities and functional boundaries. Yet, fundamentally, only two dimensions matter (ITF, 2015[67]; Noy, Shinar and Horrey, 2018[66]):

- Does the automated system seek to assist or replace the driver, i.e. is automation partial or complete?
- Does the automated system operate part of the time in some contexts or everywhere at all times?

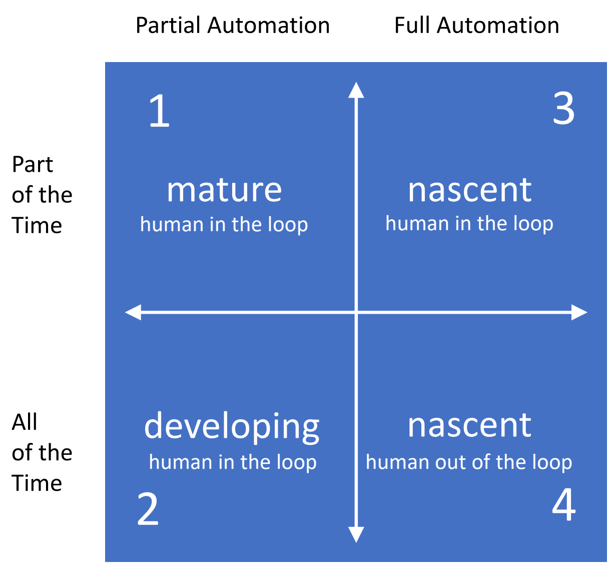
Figure 3.9. Society of Automotive Engineer's five levels of automated driving performance



Source: Based on SAE (2018[68])

Figure 3.10 depicts the categorisation of automated driving systems according to the degree and duration of the automated functions.

Figure 3.10. Two-dimensional categorisation of automated driving systems



Source: Adapted from Noy, Shinar and Horrey (2018[66]).

The ability for advanced driver assistance systems to offer partial automation part of the time is already quite advanced at present (e.g. quadrant 1: lane-keeping, automatic speed control) and the capability for systems to provide partial automation in all contexts is developing (e.g. quadrant 2: lane keeping assist, autonomous cruise control and lane-change capability, etc.). The technologies that allow full automation part of the time and in certain contexts is nascent but developing (e.g. quadrant 3: motorway autopilot or traffic jam assist). A significant gap exists, however, between those systems and ones that could completely replace human drivers in all contexts and at all times. In quadrants 1 through 3 just as in SAE levels 1-3, humans retain a significant role as driver, back-up driver and/or supervisor of the automated system. This hybridisation of roles poses inherent safety challenges (ITF, 2018[69]).

At the core of all levels of automation is the ability for automated vehicles to perceive ("sense") their environment, process this information to determine what is relevant to safely carrying out the allocated driving task ("plan"), decide on a course of action, successfully carry out this action by triggering actuating systems such as steering, braking, signalling ("act") and then assess the result of the action carried out ("assess") (Parasuraman, Sheridan and Wickens, 2000[70]). Each of these steps mimics how humans drive but, with different capabilities and at different execution speeds.

Technology is now reaching the point where the fusion of different sensors, processing systems and actuators can replicate and in some cases improve on human driving performance. This convergence is at the heart of the incipient revolution promised by highly- and fully-automated driving. But the convergence is not complete and there remain key areas where automated driving systems still lag behind the capabilities of the average human driver.

Humans still retain an advantage over single sensor-based automated systems when it comes to reasoning and anticipation, perception and sensing when driving. Overcoming this gap (and only in certain conditions) requires multi-sensor fusion on the part of the automated system. This strategy is commonly employed on various vehicle testbeds deployed in current trials. Even in the case of multiple sensor fusion, human capabilities still outperform that of automated systems in certain problematic and complex contexts. Some common traffic scenarios still confound automated driving system capabilities. Correct identification of bicycle orientation and anticipation of cyclist trajectories are also problematic. (NHSTA, 2017[71]; Schoettle, 2017[72]).

The risk stemming from these and other dangerous scenarios can potentially be mitigated by augmenting embarked sensing capabilities with inputs from other vehicles and infrastructure. The need to move from a "reactive" safety paradigm where vehicles rely solely on their embarked capabilities to a "proactive" safety framework where vehicles are embedded in a communicative network to deliver better safety outcomes is actively debated. Connected automated systems that can "see" what humans cannot (e.g. beyond line of sight) and relay this information to each other show promise for surpassing human driving capabilities. But the communicative car strategy is one that is not void of new risks and challenges – especially as concerns cyber-security risks (ITF, 2018[69]). Further, beyond correct perception and decision-making functions, the issue of the regulatory validation of system performance to determine legal road-worthiness remains challenging (Stolte et al., 2016[73]).

What makes people choose to use autonomous vehicles?

There are a number of drivers for increased automation, not all of which are aligned to support rapid deployment trajectories. Furthermore, these factors will impact not only the overall uptake of highly automated, and eventually fully autonomous, vehicles, but whether individually owned or fleet-owned and operated deployment pathways will dominate.

Safety performance, as noted, is a strong driver and one that is likely to increase if future automated driving systems are successfully able to handle a broader and broader range of operational contexts. The few automated vehicle crashes that have occurred to date, however, have tempered the attractiveness of automated vehicles in certain regions. In other regions with lower levels of motorisation (and of personal driving experience), acceptance rates for automated vehicles are much higher, for instance in China.

Acceptance may be linked to the perception and expectation for driving performance. In individually-owned automated car scenarios, passengers may be wary of systems that they perceive to drive differently than they themselves do – even if these are demonstrably safer. If, on the other hand, fleet-based commercial deployment dominate, expectations and acceptance of safe driving behaviour may be greater. Much as passengers may wish to be driven by "safe" taxi drivers, they may also wish to be driven by "safe" automated driving systems.

Increased accessibility may be an important driver of growth – especially for fleet-based systems that improve overall accessibility options. Accessibility can be especially improved for disabled, elderly and young passengers who do not have driving license and currently are using conventional public transport. Robustness to cyber-security threats will matter – especially if deployment pathways are conditioned on greater and greater connectivity.

Cost will condition the uptake of automated driving systems. The potential reduction of parking costs and the ability for former drivers to engage in other activities while being driven may increase the attraction and uptake of highly automated vehicles, especially for better-off households who already disproportionately contribute to overall vehicle-kilometres travelled. However, higher unit technology costs will likely act to contain the deployment rate of individually-owned automated vehicles – at least at the outset.

Partly because of this cost-constraint, many companies planning to deploy highly automated vehicles are planning to do so in the form of ridesourcing fleets (e.g. Waymo, Renault-Nissan, Ford). The potential of automation to reduce heavy goods vehicle and delivery van operating costs is also high and suggests the road freight sector may be one of the first to fully automate (ITF, 2015[67]; ITF, 2017[74]). Uptake in this sector may be accelerated by the scarcity of qualified human drivers against a backdrop of increased road freight demand.

Perhaps the greatest driver will be the regulatory framework deployed around automated driving. This is an area of great uncertainty, as it is itself linked to the still-developing understanding of the safety and traffic impacts of the technology. Permissive testing regimes as enacted by many jurisdictions today do not necessarily pre-figure permissive homologation and licensing regimes. Further, a number of regional and city transport authorities have indicated willingness to put in place constraining regulatory regimes given the potential for automated driving systems to exacerbate traffic congestion and city sprawl. If, how and under what form these regimes are put into place, and their robustness to legal challenges, remains unknown at present.

What impacts do autonomous vehicles have on urban transport?

As with any technology, vehicle automation will bring benefits but will also have negative impacts. Many benefits and negative impacts are foreseeable and the former should dominate the latter in any deployment scenario. However, the deployment of such a new and disruptive technology will also have unforeseeable benefits and negative impacts – the balance of which is uncertain but likely in favour of the former.

One of the key uncertainties in relation to the large-scale deployment of automated vehicles relates to the impact on overall vehicle-kilometres travelled, congestion and substitution effects with public transport and active mobility.

In uptake scenarios that are characterised by individual use of highly automated vehicles, the vehicle-kilometres travelled may well increase – significantly in certain cases. Wadud, MacKenzie and Leiby (2016[75]) estimate that the increase in annual vehicle-kilometres due to induced demand from underserved user groups (youth, elderly, disabled) will be between 2% and 10%. Harper, Hendrickson and Samaras (2016[76]) suggest that the upper bound of that increase will be equal to 14%, while Brown, Gonder and Repac (2014[77]) estimate a much higher increase of 40%. Childress et al. (2015[78]) arrive at a 20% increase in vehicle-kilometres travelled, assuming 30% larger road capacity, 65% lower value of travel time, and 50% decrease in parking costs. Schoettle and Sivak (2015[79]) put the increase in annual vehicle-kilometres at 75% and consider a 43% reduction in vehicle ownership. For Fagnant and Kockelman (2015[64]), the increase in vehicle-kilometres travelled depends on the market penetration rate of autonomous vehicles. At a 10% market penetration rate, they calculate a 2% increase in vehicle-kilometres, while at a 90% penetration rate vehicle-kilometres grow also by 90%.

Gruel and Stanford (2016[80]), using a system dynamics approach showed that in all the scenarios they considered, v-km is likely to increase, leading to a potential increase in energy consumption and emissions in total. The order of magnitude of the increase differs significantly across the scenarios. In the scenario assuming that the mode choice is not affected autonomous vehicles bring mostly benefits. In the scenario of highly increased attractiveness of travelling by car the v-km travelled grow significantly, with corresponding growth of congestion level and emissions, and urban sprawl. In the sharing scenario car ownership decreases but the vehicle-kilometres grow even more due to the reallocation trips. Other studies also point to vehicle-kilometre increases in fleet operation of fully automated ridesourcing services (WEF/BCG, 2018[81]). Fleet-based deployment of automated vehicles may lead to impacts similar to those seen in conjunction with the uptake of ridesourcing services – generally an increase in vehicle-kilometres travelled in early phases of deployment (ITF, 2018[39]). This impact may be mitigated over time if a large share of individual car users switches to these systems – especially in conjunction with public transport or active transport.

However, the ITF (2015[56]; 2016[53]; 2017[55]) in its simulation studies on shared mobility showed that if there is a centralised dispatcher optimising the reallocation of the shared vehicles, the number of vehicle-kilometres travelled may not grow. Parking spots and depots for idle vehicles will be needed across the city in this case.

The link between vehicle-kilometres and congestion impacts of highly automated driving depend on three main factors (Anderson et al., 2016[65]). All else equal, an increase in vehicle-kilometres might mechanically increase congestion levels. The potential reduction in road crashes and their severity will lead to lane closures and delays, increasing overall traffic flow reliability. Congestion may be further reduced, all else held equal, due to more even traffic flow and optimised speed performance (Simonite, 2013[82]). Tientrakool, Ho and Maxemchuk (2011[83]) estimated in their study that use of autonomous vehicles can increase road capacity by 273%. The potential for improved junction throughput with automation is also significant (Tientrakool, Ho and Maxemchuk, 2011[83]). As with traditional congestion-reduction efforts, this potential is only realised if it is locked-in with demand management techniques such as pricing that reduce or eliminate the induced traffic effect (ITF, 2018[39]).

Wide scale deployment of autonomous vehicles can release parking spaces in city centres for other needs. However, improved accessibility and possibility for the driver to perform other activities instead of driving might stimulate urban sprawl and growth of suburbs with decrease of the population density of metropolitan areas. This, in turn, will lead to more vehicle-kilometres travelled and an increase in related CO_2 emissions, pollution, and energy use. Increased sprawl-related vehicle-kilometres might lead to higher congestion levels.

Adoption of full or even partial automation may lead to more efficient driving in terms of speed, smoother acceleration and deceleration, which, in turn, will reduce fuel consumption. In the case of congestion reduction the speed will be even more stable. This can lead to up to 10% of fuel economy (NRC, 2010[84]). The increased level of safety might also allow to the manufacturers to produce lighter vehicles and, due to that, the fuel consumption can be additionally reduced up to 14% (Bagloee et al., 2016[85]). However, increased vehicle-kilometres will have the opposite effect. Fuel consumption can grow 10-40% according to different studies presented above (assuming that the fuel consumption increases in proportion with vehicle-kilometres).

Simulation results

The ITF's modelling framework was also used to test an autonomous vehicle scenario to assess the possible impact of autonomous private and shared cars, as well as autonomous public transport modes (e.g. buses), on urban transport demand and CO_2 emissions. In this scenario assumes that 25%-40% of car trips are autonomous by 2050, depending on the region (in contrast to the current ambition scenario, which assumes that 0%-2.5% of car trips are autonomous by 2050).

The assumptions made in this scenario account for changes in the usage costs of the respective modes, for gains in productive time of vehicle passengers (that would have been drivers in a non-automation scenario), and for potential increases of empty vehicle-kilometres where parking restrictions or charges apply (i.e. vehicles cruising without passenger). The changes in the usage costs of the different transport modes have varied impact on travel and mode choice around the globe, and depend on the relative cost structures of the different modes of transport in the base year and the current ambition scenario.

In most regions, vehicle automation is likely to increase passenger-kilometres. This is mainly due to a decrease in the cost of automated shared mobility or public transport (compared to a scenario without automation) which results in higher uptake rates of these modes that often entail detours for the travellers. The high occupancy rates of these services allow congestion levels to decrease, and CO_2 emissions to decline, despite the higher number of total passenger-kilometres travelled.

Table 3.5. Projected impact of an autonomous vehicle scenario

Percentage change compared to current ambition scenario

Region	Passenger-kilometres		CO_2 emissions	
	2030	2050	2030	2050
Africa	-1	5	-2	0
Asia	-1	-1	-3	-10
China and India	1	5	0	0
Middle East	-2	-6	-3	-11
Transition	0	2	0	0
Latin America	-3	0	3	-4
OECD Pacific	-1	1	-2	-7
EEA and Turkey	1	7	0	0
North America	-1	-3	-1	-7

Box 3.4. Drones in the transport system

Drones are already being deployed in the transport sector to survey and monitor the condition of infrastructure. In the near future they will also offer innovative services in freight delivery and passenger transport. With the sector developing at a rapid pace, transport policy makers need to create frameworks for drone use that allow innovation while ensuring that society benefits as a whole. The general public may not be ready to fly on pilotless aircrafts (though much of current flight is already automated), but as with advances in self-driving cars, buses and trucks, drone technologies are quickly moving from science fiction to providing services in the real world.

Technological advances have enabled the manufacture of new types of airborne vehicles and the integration of these vehicles within existing (air) transport systems (Schwab, 2016[86]). Although demand for freight and passenger transport is increasing worldwide, many regions lack adequate surface access to potential markets. Particularly in developing and emerging countries, the introduction of reliable and efficient drone services could significantly improve regional connectivity. Aiming to take advantage of such economic opportunities, the private sector has been the main driving force behind the development of drones and it is currently experimenting with novel service applications for a variety of uses.

The potential impacts of large commercial drone fleets are as yet not fully understood. Assessment of their potential impact on aviation has begun, but appraisals are rarely addressed from a cross-sectoral perspective. Freight drones for urban goods deliveries and, eventually, drones for passenger travel, may have both positive impacts (e.g. improved connectivity in remote regions, alleviation of traffic congestion, reduced travel times) and negative impacts (e.g. issues related to safety, privacy, noise, energy consumption, land use and visual amenities) (Schechtner et al., 2018[87]). Policy makers also need to focus on the impact of the potentially millions of "drone ports" and their integration into the transport system and society as a whole.

Drone market forecasts vary considerably, but consensus generally exists regarding the fact that drones will constitute a multi-billion dollar market within the next five to ten years. One global report estimated USD 127 billion for a civil-drone powered solutions market for addressable industries (PwC, 2017[88]). A 2018 global survey by Blyenburgh (2018[89]) expected a three-fold increase in freight drone missions for 2017-2018, and global players such as Alphabet and Amazon are already trialling both passenger and freight drone operations across the globe.

How far citizens are willing to go to accept the deployment of drone fleets will depend on their understanding of the balance of benefits and disbenefits and on the successful mitigation of potentially adverse effects. Research to quantify impacts is still scarce; therefore ITFs ongoing working group on Drones in the Transport System of the Future is collating global expertise to advance the understanding of the impact of drones.

Disruptive scenarios for urban passenger transport

This section analyses the combination of three possible future disruptions of transport: teleworking, massive shared mobility and autonomous vehicles. The potential impacts of disruptions in urban passenger transport are uncertain at best. This uncertainty relates to their effect on travel behaviour and transport demand, on people's destination and route choices, on mode shares on spatial accessibility, and on externalities of the transport system such as emissions or congestion. Also uncertain is the future structure of the urban transport industry ecosystem and the arrival and regulation of new actors and services, and the role for incumbent service providers and manufacturers. The overall impact of these disruptive developments will depend on if, and to what degree, they happen independently from each other (e.g. some disruptions may not develop to a significant degree at all), whether they happen in a phased manner (e.g. some disruptions happen before or after other disruptions), or whether they happen simultaneously and may reinforce each other, whether for better or worse.

The impact of disruptions will also depend on policy measures in place as the disruptions evolve and gain importance. Poorly aligned policies may exacerbate potential negative impacts such as congestion or emissions. Adapted policies can ensure that negative impacts are reduced or eliminated as new services and technologies scale up to meet future urban transport demand.

Two illustrative disruption scenarios for urban areas that assess the impact of *policy measures* on the future of urban transport systems are presented below. Both assume that automated driving, massive shared mobility and teleworking are taken up simultaneously.

However, in the first scenario the disruptive developments play out in an environment where policies do not seek to guide outcomes relating to car use and access (e.g. parking pricing, curb pricing or urban vehicle access regulations), public transport use or the uptake of active modes. Explicit policy guiding the evolvement of disruptions and basic data syntax are absent; interoperability requirements and open access requirements are not met, and hence Mobility as a Service (MaaS) is poorly deployed and exists only in a few niche areas. This is the unmanaged disruption scenario.

In contrast, the managed disruption scenario assumes guiding policies are in place. A broad, supportive and open Mobility as a Service (MaaS) ecosystem helps citizens adopt new travel behaviours. In this scenario, seamless multi-modal trips are so convenient, reliable and affordable that in many instances they become more compelling than single-occupancy car trips.

Table 3.6 summarises the specifications for the managed and unmanaged disruption scenarios, in the context of the high ambition scenario. Both assume other developments that favour transport CO_2 reduction, such as the electrification of vehicle fleets (in line with the IEA's EV30@30 scenario). This is to reflect that such CO_2 reduction ambitions will likely progress independently of other technological developments that may disrupt the transport sector.

The simulation results show that disruption without guiding policy action leads to unwanted outcomes. Disruption does not do away with the need for policy. Rather, it necessitates a recalibration of regulatory frameworks to deliver what citizens expect and public authorities are tasked to ensure. The lack of adequate restrictions on single-occupancy vehicles in the unmanaged disruption scenario, for example, results in a significant shift from shared services to private vehicles compared with the managed disruptions scenario for urban areas. This is because vehicle automation reduces travel costs for the users and increases the experienced utility of travel (since travel time can be used for other activities than driving).

The importance of integrating shared mobility options with other transport services is another important insight of the unmanaged disruption simulation. Integration allows travellers seamless interchanges between different transport modes, while a lack of integration means that single-occupancy car trips remain more attractive and reliable than multi-modal trip chains.

Strong access restrictions for single-occupancy vehicles in dense urban areas combined with a robust and compelling MaaS ecosystem have the potential to reverse the trend of increasing private car use. This would benefit society by reducing many of the negative externalities associated with single car use in dense urban environments and, more generally, the emission of pollutants and CO_2. It would also benefit individual citizens by putting more reliable, convenient, comfortable, and affordable travel options at their disposal.

Table 3.6. Disruptive scenario specifications for urban passenger transport

Variables	High ambition	Unmanaged disruption	Managed disruption
Disruptive developments			
Telework	3-25% of trips are affected by 2050, depending on the region	3-30% of trips are affected by 2050, depending on the region	3-30% of trips are affected by 2050, depending on the region
Shared mobility	Provision of shared modes follows past trends	Provision of shared modes at twice the speed of past trends	Provision of shared modes at twice the speed of past trends
Autonomous driving	0%-2.5% of car trips are autonomous by 2050, depending on the region	25%-40% of car trips are autonomous by 2050, depending on the region	25%-40% of car trips are autonomous by 2050, depending on the region
Mitigation measures			
Transport integration/MaaS	50% of travellers use MaaS solutions to plan their journeys by 2050,	20% of travellers use MaaS solutions to plan their journeys by 2050	100% of travellers use MaaS solutions to plan their journeys by 2050
Access restrictions for cars	40% of car trips affected by 2050	20% of car trips affected by 2050	60% of car trips affected by 2050
Parking pricing	Parking prices increase 10-40% relative to expected purchasing power, depending on the region	Parking prices increase 0-20% relative to expected purchasing power, depending on the region	Parking prices increase 10-40% relative to expected purchasing power, depending on the region

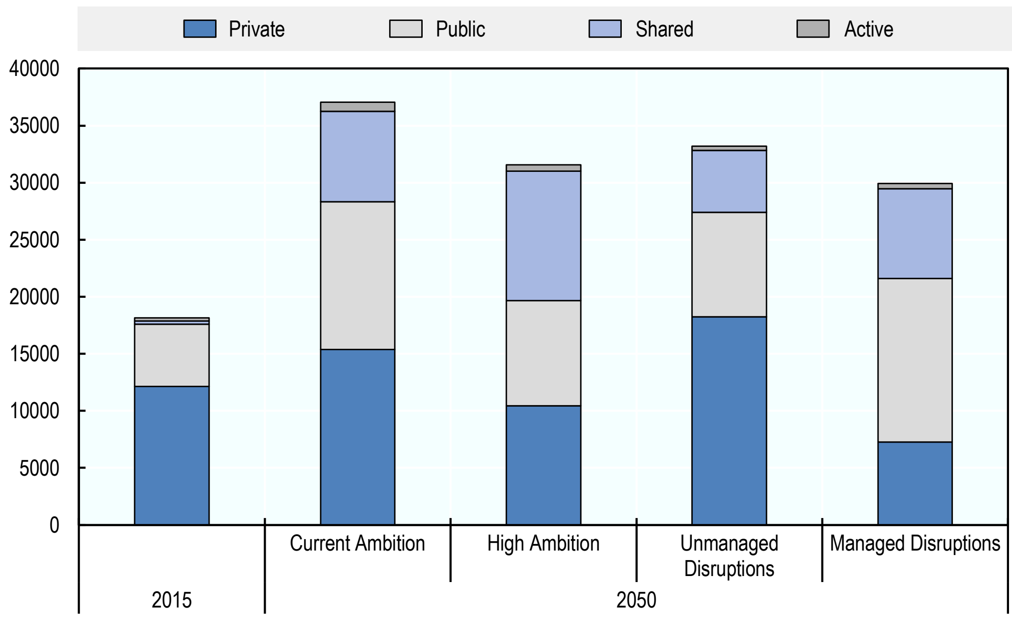
Note: For all scenarios, electric vehicle uptake follows the EV30@30 scenario. Land-use measures result in a densification of urban regions by 5-10% by 2050. The supply of mass public transit in all regions follows past trends in Europe.

The managed disruption scenario illustrates that policies have a major impact on future urban modal shares (Figure 3.11). An optimal integration of different transport options in a MaaS ecosystem can result in a significant increase in the share of public transport-like services and meet mobility demand with significantly fewer vehicles. In the managed disruption scenario, public transport modes (bus and rail) cover almost 50% of all passenger-kilometres by 2050, while total vehicle-kilometres decrease by 19% compared to the current ambition scenario. That said, the simulation is agnostic as to how the public transport-like travel is provided – many models are possible and it is likely that what is today called "public transport" will comprise a growing diversity of actors, ideally operating under more flexible and performance-based rules.

Relative energy and operating prices will also play a role, in sometimes unexpected ways. The share of private modes in urban areas drops significantly between 2015 and 2050 in the current ambition, high ambition and managed disruption scenarios, but not in the unmanaged disruption scenario Table 3.7.

Figure 3.11. Global urban mobility by mode of transport and scenario, 2015-50

Billion passenger-kilometres



Note: See glossary for further information on mode grouping

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CO_2 emissions from urban transport in 2050 are substantially lower in all scenarios considered when compared to the current ambition scenario. This is an encouraging – albeit partial – result, as it suggests that even unmanaged disruption on top of likely future policies will lead to a drop in the amount of CO_2 emissions from urban transport. CO_2 emissions in the unmanaged disruption scenario lie between those under the current and high ambition scenarios (see Figure 3.12 and Table 3.8).

This is largely the result of an increased mode share of single-occupancy cars due to the increased uptake of automated driving in the unmanaged disruption scenario. When autonomous driving takes market share away from available shared mobility services, CO_2 emissions rise, all else held equal. Thus, overall urban transport-related CO_2 emissions grow by almost 50% in the unmanaged disruption scenario when compared to the high ambition scenario. However, CO_2 emissions in the unmanaged disruption scenario remain well below those in the current ambition scenario.

The importance of guiding policies becomes evident when comparing urban transport CO_2 emissions in the managed disruption and unmanaged disruption scenarios. The creation of a comprehensive MaaS ecosystem that integrates public transport and other forms of shared mobility helps to rein in the potential CO_2 emissions increase from the uptake of automated vehicles. CO_2 emissions from urban travel are similar in the high ambition and managed disruption scenarios precisely because policies are in place that restrain the growth in the total distance travelled by automated vehicles with a single occupant.

Table 3.7. Projected urban mode shares by world region and scenario, 2015 and 2050

Percent of total passenger-kilometres

Regions	Private modes					Public transport				
	2015	2050				2015	2050			
		CA	HA	UD	MD		CA	HA	UD	MD
Africa	61	46	39	56	29	36	43	41	33	60
Asia	63	44	32	45	21	34	40	39	40	62
China and India	59	34	29	46	21	38	35	25	28	46
EEA and Turkey	65	25	30	65	20	30	44	25	20	42
Latin America	52	30	30	51	21	46	51	40	36	60
Middle East	78	59	45	63	30	20	31	36	28	57
North America	94	66	41	82	39	3	9	7	6	15
OECD Pacific	62	35	27	52	18	33	40	30	29	51
Transition	59	39	35	53	22	38	47	43	37	64
Regions	**Shared transport**					**Active modes**				
	2015	**2050**				**2015**	**2050**			
		CA	**HA**	**UD**	**MD**		**CA**	**HA**	**UD**	**MD**
Africa	0	9	17	9	9	2	3	2	2	1
Asia	0	14	26	14	16	2	2	2	1	2
China and India	1	29	44	25	32	2	2	2	1	2
EEA and Turkey	1	26	42	14	34	3	5	3	2	4
Latin America	1	18	28	12	18	1	2	1	1	1
Middle East	1	8	17	7	12	1	2	2	1	1
North America	3	24	51	12	45	0	1	1	0	1
OECD Pacific	3	24	41	18	30	1	2	2	1	1
Transition	1	11	20	9	12	2	3	2	1	2

Note: CA: current ambition scenario; HA: high ambition scenario; UD: unmanaged disruption scenario; MD: managed disruption scenario.

Table 3.8. Total urban transport CO2 emissions by world region

Four alternative scenarios, million tonnes

	2015	2050			
Region	**Base year**	**Current ambition scenario (CA)**	**High ambition scenario compared to CA**	**Unmanaged disruption scenario compared to CA**	**Managed disruption scenario compared to CA**
Africa	86	186	-62	-52	-66
Asia	150	211	-67	-56	-69
China and India	409	319	-69	-48	-74
EEA and Turkey	187	84	-66	-34	-70
Latin America	197	193	-61	-47	-61
Middle East	91	142	-63	-53	-68
North America	853	547	-81	-69	-84
OECD Pacific	247	111	-73	-61	-73
Transition	61	46	-57	-43	-63
Global	2281	1839	-70	-56	-73

The congestion effects of travel activity also underline the need for policy guidance where disruptive developments occur. Congestion effects are measured here by comparing the modelled on-street traffic flows with the capacity of the available street network. The closer the ratio between these two measures, the more congested is the road network. Figure 3.13 and Table 3.9 compare congestion levels of each alternative scenario with the current ambition scenario. In the unmanaged disruption scenario, congestion levels in urban areas increase by 38% globally. The marked increase in projected congestion in Europe in the unmanaged disruption scenario results from increasing distances travelled by autonomous vehicles and from high levels of private car use facilitated by increasingly affordable electric vehicles. In the absence of infrastructure changes and more efficient shared mobility services, these factors result in significantly increased congestion in Europe. However, the guiding policies implemented in the managed disruption scenario effectively reduce congestion levels below the current ambition scenario, and even below the high ambition scenario. So while any disruption scenario can lead to substantial CO_2 reductions up to 2050 - more so when guiding policies are put in place – congestion levels can be expected to increase if adequate guiding policies are missed.

Figure 3.12. CO_2 emissions from urban transport by mode and scenario

Million tonnes

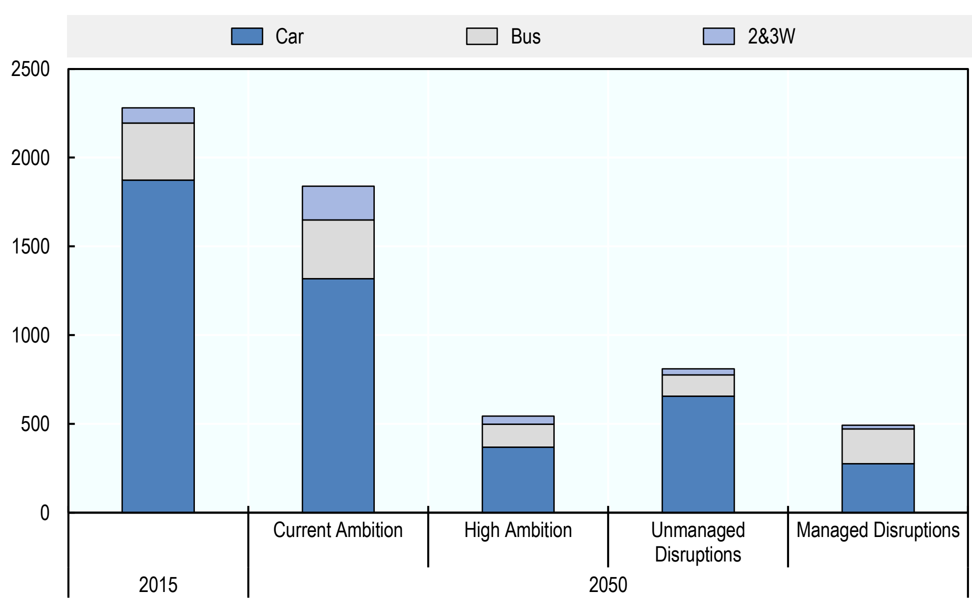

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Table 3.9. Projected urban congestion levels by world region, 2050

Percentage change compared to current ambition scenario

Region	High ambition scenario	Unmanaged disruptions scenario	Managed disruptions scenario
non-OECD	-16	36	-24
OECD	-20	43	-21
Africa	-16	20	-31
Asia	-26	8	-43
China and India	-20	52	-17
EEA and Turkey	7	113	7
Latin America	3	55	-5
Middle East	-22	3	-42
North America	-39	5	-36
OECD Pacific	-36	7	-42
Transition	-9	36	-28
Global	-17	38	-24

Figure 3.13. Projected global urban congestion levels, 2050

Three scenarios, percentage change from current ambition scenario

StatLink http://dx.doi.org/10.1787/888933972677

Table 3.10. Urban mobility by world region, 2050

Four alternative scenarios, billion passenger-kilometres

	2015	2050			
Region	Base year	Current ambition scenario (CA)	High ambition scenario (% change from CA)	Unmanaged disruptions scenario (% change from CA)	Managed disruptions scenario (% change from CA)
Africa	982	3 787	1	7	-2
Asia	1 546	3 825	-11	-8	-17
China and India	4 865	11 833	-13	-7	-17
EEA and Turkey	1 733	2 695	-14	-8	-18
Latin America	2 180	3 924	-13	-8	-16
Middle East	619	1 446	-12	-9	-17
North America	3 504	5 920	-30	-28	-34
OECD Pacific	2 164	2 803	-29	-27	-32
Transition	571	808	-1	2	-8
Global	18 164	37 040	-15	-10	-19

Notes

[1] See www.itf-oecd.org/outlook for model details.

[2] Excluding public transit; see glossary for more details.

[3] See glossary for a definition of free-floating.

[4] OECD Pacific countries include Australia, Japan, New Zealand and South Korea; transition economies include Former Soviet Union countries and non-EU south-eastern European countries.

[5] Although flexible working arrangements involving teleworking that do not reduce trips to the office can also have an impact on travel demand patterns and congestion, the emissions reductions resulting from these arrangements is assumed to be lower than teleworking activity that reduces total trips to the office.

[6] Since the PGi survey sample targets digitally-enabled workers, it likely overestimates the proportion of teleworkers in the total employed population.

[7] https://www.federalreserve.gov/publications/2018-economic-well-being-of-us-households-in-2017-employment.htm

[8] Non-transport related impacts are numerous, ranging from increased productivity, reduced exposure to air pollution, increased accessibility to employment, and greater employee well-being.

[9] Ben-Elia et al. (2018) also call for future research on the relationship between ICT (including teleworking activity) and travel behaviour that addresses the possible simultaneity between the two as well as the possibility that unobserved confounding factors may be responsible for the direct impacts that have been documented thus far.

[10] In 2018, the ITF published a report entitled Safer Roads with Automated Vehicles? (ITF, 2018a), on which much of this section is heavily based.

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Chapter 4. Disruptions in non-urban passenger transport

This chapter assesses the impact of potential disruptions on non-urban passenger travel. Three disruptions are considered: a further expansion of low-cost aviation into long-haul services, the introduction of ultra-high-speed rail services and the large-scale availability of alternative fuels for aviation. Beyond the two scenarios outlining future pathways for transport under policies reflecting either current ambitions or high ambitions, three additional scenarios are examined. These look at the combined impacts of the potential disruptions identified for non-urban passenger transport and provide projections for the development of non-urban travel demand and its CO_2 emissions to 2050.

Demand for non-urban passenger transport set to rise sharply

Non-urban travel is estimated to have made up nearly 60% of global passenger travel in 2015. Global demand for domestic and international passenger transport will increase by 225% between 2015 and 2050 if current trends continue. It will thus grow more than twice as fast as urban transport demand, which is projected to increase by 104% over the same period. The main drivers of this growth are rising incomes and population growth. It will be especially high in developing countries and for long-distance travel, for instance for non-urban domestic rail travel and international air travel.

In terms of CO_2, non-urban passenger travel was responsible for about half of all passenger transport emissions in 2015. The projected demand growth will push the share of CO_2 emissions from transport much higher: in 2050, it could represent two-thirds of all passenger transport CO_2 emissions. A second factor in this growth is the lack of concrete decarbonisation policies for non-urban transport. This contrasts starkly with the many policy instruments in place that target the effects of car use and emissions in urban areas. Arguably, this policy gap exists because many downsides of urban mobility, such as congestion and air pollution, have a more immediate impact on people's lives than those of non-urban transport.

For the purposes of this study, non-urban passenger travel consists of both international and domestic mobility. International travel involves trips between two countries by road (bus and car), rail and air. Domestic travel refers to non-urban trips within the same country. Domestic travel can be further split into travel between urban areas (inter-urban travel, carried out by road, rail or air), and regional travel (within the same region but originating outside urban areas, carried out by road and rail).

The non-urban transport sector has not seen major disruptions during the past few decades. The major change has been strongly growing demand since the early 2000s, especially for international air travel. This may change, however. Several disruptive developments could affect non-urban transport and inter-urban passenger travel in particular. Each of them may influence demand, mode choice or externalities to differing degrees, and not always in beneficial ways. Their impact will also depend on the political, social, geographical or economic context and therefore differ from country to country or region to region.

The following analysis considers three potential disruptions of non-urban passenger travel:

1. *The expansion of low-cost airlines into long-haul aviation:* Low-cost airlines already offer medium- and long-haul flights, but not to the extent that they are present in short-haul markets. An increase in the number of low-cost operators in long-haul markets could drive airfares down and further stimulate demand for international air travel.

2. *The rise of ultra-high speed surface transport:* Ultra-high speed surface transports such as Maglev and Hyperloop already exist or are in the planning phase in some parts of the world, but are not yet widely available. A potential extension of the current high speed rail (HSR) network and the construction of new surface links using Maglev and Hyperloop may generate new demand or divert demand from aviation, even if they are unlikely to become a large-scale alternative for air services (de Rus, 2008[1]).

3. *The large-scale availability of alternative fuels in aviation:* Alternative energy sources for aviation such as electricity or synthetic fuels offer the potential of carbon-free or zero net emissions aviation. This would enable the sector to grow even under a strict policy environment requiring aviation to drastically reduce its CO_2 emissions reductions

The three primary disruptions examined in this chapter will not have a direct impact on road transport beyond modal shift. Carbon related costs will have a smaller impact on road travel as low-emission or no-emission options already exist for road vehicles. Other developments also stand to disrupt non-urban passenger transport in future years. Road transport, which represents nearly 40% of inter-urban trips, could be affected by developments such as autonomous and electric vehicles and shared mobility. In this Chapter, shared mobility for the non-urban context refers to carpooling or other sharing services that increase average vehicle occupancy. While the impact of these disruptions is likely to be smaller in non-urban travel compared to urban passenger travel, they should not be disregarded.

A range of potential policy decisions may also affect the cost of non-urban travel, and hence demand. Most notably, a growing awareness of the climate impacts of CO_2 emissions is leading to policies to mitigate the externalities of burning fossil fuels. In the aviation sector, the International Civil Aviation Organization (ICAO) has adopted a new aircraft CO_2 emissions standard (ICAO, 2017[2]) and is also implementing the Carbon Offsetting and Reduction Scheme for International Aviation, known as CORSIA (ICAO, 2016[3]). Under CORSIA, aircraft operators will collectively offset CO_2 emissions that exceed a threshold based on the average level of CO_2 emissions in 2019/20. CORSIA will become mandatory in 2026, following a trial phase between 2021 and 2023 and a voluntary phase from 2024 and 2026. A few exceptions will be made, for instance for least-developed countries.

The mitigation potential of transport policies for non-urban passenger travel

The International Transport Forum (ITF) has developed a global non-urban passenger transport model which assesses transport demand, mode shares and related emissions under various policy scenarios for non-urban passenger travel in all world regions to 2050.

The two main scenarios examined in this chapter are a current ambition scenario and a high ambition scenario. Both reflect the trends that may impact non-urban travel; they differ in their assumptions on the level of adoption of policies aiming to reduce CO_2 emissions from non-urban travel. The current ambition scenario extrapolates the current trajectory of technologies and policies in a business-as-usual approach. Technological advances, policy decisions and investments occur as foreseen today according to existing measures as well as already-announced mitigation commitments. Open Skies policies follow current trends, while the share of seats offered by low-cost airlines remains stable. Overall aviation demand grows in line with GDP and population projections. Aircraft fuel efficiency improves and the relative cost of air travel falls over time following current trends and fuel costs.

Such policies raise transport costs for all modes that rely on fossil fuels. In the current ambition scenario, alternative energy sources remain too expensive to compete with fossil fuels, and electric aviation would only appear towards mid-century. With regard to surface modes, fuel efficiency standards are in place for car, bus and rail. Only currently planned high speed rail lines are built. The share of autonomous vehicles in non-urban travel remains marginal, while shared non-urban travel by private car see a marginal increase. These assumptions for surface travel are in line with the International Energy Agency's New Policies Scenario (IEA, 2018[4])

The high ambition scenario reflects more advanced aspirations surrounding the deployment of technology and implementation of policies. The details of the two scenarios for non-urban travel are summarised in Table 4.1.

Table 4.1. Current and high ambition scenario specifications for non-urban transport

Mitigation Measures		
Carbon pricing	USD 100 per tonne of CO_2	USD 500 per tonne of CO_2
Efficiency improvements and electric vehicles	The share of electric vehicles in use varies between 0.4% and 17.4% for cars and between 1% and 31.7% for busses across regions	The share of electric vehicles in use varies between 29.4% and 53.7% for cars and between 10.5% and 56.5% for busses across regions
Potentially disruptive developments		
Long-haul low-cost carriers	Very low share of low-cost carriers o long-haul flights (current trend)	Very low share of low-cost carriers on long-haul flights (current trend)
Energy innovations in aviation	Alternative fuel cost four times higher relative to 2015 conventional fuel prices Range of electric planes increases up to 1 000 km by 2050	Alternative fuel cost three times higher relative to 2015 conventional fuel prices Range of electric planes increases up to 1 600 km by 2050
Autonomous vehicles	Share of autonomous vehicles in use varies between 0% and 2.5% for cars and 0% and 1.25% for busses across regions	
Shared mobility	The percentage of shared trips of total car trips equals 6.7%	The percentage of shared trips of total car trips varies between 13.3% and 20% across regions
Ultra-high-speed rail	High speed rail operational where current projects exist or are planned	High speed rail operational where current projects exist or are planned

Note: Values for electric vehicles based on IEA (2018[4]) for the current ambition scenario and IEA (2018[5]) for the high ambition scenario.

The carbon price for each scenario reflects a global average. In reality, the level of carbon pricing will vary between regions. Under the current ambition scenario, carbon taxation and offsets reach USD 100 by 2050. In the high ambition scenario, carbon-related prices reach USD 500 by 2050. This reflects greater mitigation ambitions outlined by international agreements and specific national governments. For instance, France aims to raise the price of one tonne of CO_2 to EUR 250 by 2030 (Quinet, 2019[6]).

Box 4.1. Changes in the non-urban passenger mobility assessment framework

The previous ITF's international aviation model has been extended to include all non-urban passenger mobility in all main passenger modes (except maritime passengers' movements such as cruise shipping that are mainly recreational and not a derived transport activity).

The model separates the inter-urban traffic from the regional traffic not measured already in the urban passenger model. The inter-urban traffic is assessed using a four-step model approach that starts with the setting of the travel demand – propensity to travel (for different travel ranges), continues with destination choice, mode choice and finally route assignment. All this is developed under a unified model where surface modes can be used as "feeding" modes to aviation and the propensity to travel of all modes is inter dependent while allowing for modal transfers to occur.

The regional model results originate from a travel activity generation model; the travel demand is then split among the surface modes available in each region, given the local context variables (e.g. infrastructure, car ownership).The model is presented in more detail in Annex 4. The main changes can be summarised in the following:

1. *Greater degree of disaggregation:* The newest model has 1 191 centroids, which are the source of all intercity activity in the world. They were identified from all medium and large size airports in the world that have an international air traffic license. Airports are clustered in city airport codes, when they are considered as such by ICAO or when they are within 100 km of the main airport and within the same country.
2. *Incorporation of national and regional traffic:* The model is able to assess the development of domestic travel as well of the regional traffic and how they may be influenced by transport policies or exogenous factors.
3. *Propensity to travel instead of propensity to fly:* The model incorporates the concept of modal availability in several ranges of travel. It also examines mode alternatives that may occur in the future following the development of new transport infrastructure or changes in the cost of travel for any mode.
4. *Intermodality:* The access to an airport within a region may be performed by surface modes (e.g. rail, car or bus), which allows expanding the influence area of city airports and reduce some over estimation of seeding air travel.

Today's policies will not decouple demand for non-urban transport from emissions

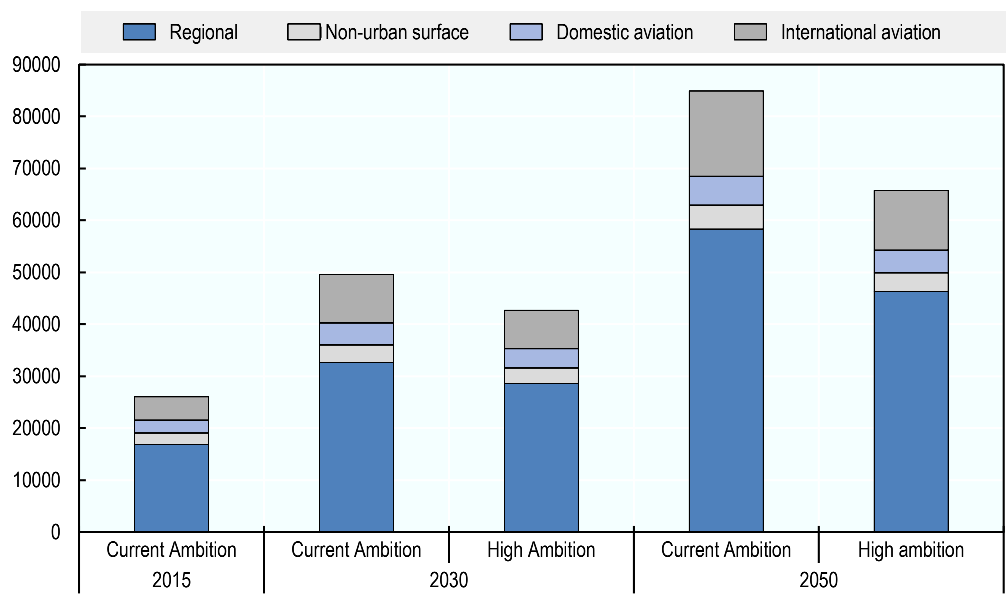
Total non-urban travel reached an estimated 26 000 billion p-km in 2015. Of these, 17 000 passenger-kilometres represent regional travel. By comparison, air travel represented 7 000 billion p-km. By 2050, the total number of passenger-kilometres travelled in a non-urban setting is estimated to reach 85 000 billion p-km, of which almost 60 000 billion would be regional travel. In terms of CO_2 emissions, regional travel is responsible for 51% of all non-urban CO_2 in 2015, a figure that grows to 67% by 2050.

As a result of existing policies and goals targeting improvements in fuel efficiency in all modes and increased electrification of surface modes, non-urban transport CO_2 emissions are expected to grow significantly less than passenger-kilometres. In the current ambition scenario, non-urban travel grows by 225%, while CO_2 emissions increase by 74%.

Regional travel is a major part of non-urban travel and the main driver of emissions in this scenario (Figure 4.1 and Figure 4.3). In the base year 2015, regional travel corresponds to two thirds of all non-urban travel demand, a figure that is expected to grow to 70% by 2050.

Figure 4.1. Projected non-urban transport demand by sector and scenario to 2050

Billion passenger-kilometres



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Domestic travel and emissions in non-OECD countries are set to increase drastically under assumptions of the current ambitions scenario. By 2050, domestic non-urban transport grows by 332% in non-OECD countries, driven by the growth of population and GDP. By comparison, the projected increase in OECD countries is only 35%.

The difference is even more pronounced in terms of CO_2 emissions. The policies planned in OECD countries with regard to the vehicle fleet can reduce emissions by 40% compared to 2015 levels. Non-OECD countries are not able to address the growing demand despite technological developments in the current ambition scenario. As a result, total non-urban emissions increase by 181% to 2050. The strongest growth in both non-urban transport demand and CO_2 emissions is expected in Asia (excluding India, the People's Republic of China and OECD Pacific) and Africa (Figure 4.3). In Asia especially, non-urban travel and related emissions grow at the same rate. India and China would remain the biggest absolute contributor in both passenger-kilometres and emissions, but the rest of Asia is catching up fast in both parameters.

Aviation will see high growth in both domestic and international markets. Air travel demand is boosted by more Open Skies agreements (ITF, n.d.[7]) and relatively cheap air fares due to improved fuel efficiency of aircraft and stable long-term fuel price projections (IEA, 2018[5]).

International aviation reaches the highest compound annual growth rate of all non-urban travel modes, with 3.8% through 2050. Thus, international flights would provide a total of 16 500 billion p-km in the current ambition scenario that is 3.6 times the 2015 volume. Domestic aviation also grows fast, but less than international aviation since short-haul flights face direct competition from surface modes. Nevertheless, domestic aviation more than doubles volume to 2.2 times the 2015 level, reaching 5 520 billion p-km.

The air network grows with an average annual rate of 2.8% between 2015 and 2050. The highest growth is expected in developing countries, especially in Asia (excluding China and India). Despite aircraft fuel efficiency improvements in new generation aircraft, total aviation CO_2 emissions in 2050 are estimated to be 49% higher than 2015, reaching 1 061 million tonnes. As surface modes are also experiencing massive growth in this scenario, the share of aviation emissions to the total non-urban emissions decreases from 30% in 2015 to 25% in 2050.

In terms of passenger numbers, Africa, Asia and Latin America will see the strongest increases to 2050, with demand driven by growing incomes. Almost 180 million passengers are expected to travel between these regions and North America in 2050, compared with 63 million in 2015. China and India generate the most new demand for international aviation in the current ambitions scenario; a finding in line with projections by the International Air Transport Association (IATA, 2016[8]) By 2050, almost one billion trips by air will originate from these two countries, compared to 130 million in 2015. Almost two thirds of this new demand is directed towards other Asian countries, however (Table 4.1). Aviation markets in developed economies, notably in particular Europe and North America, are already liberalised and saturated. In conjunction with competition from high speed rail, this limits the growth of aviation in these regions.

Table 4.2. Projected passenger numbers for international air travel between regions, 2050

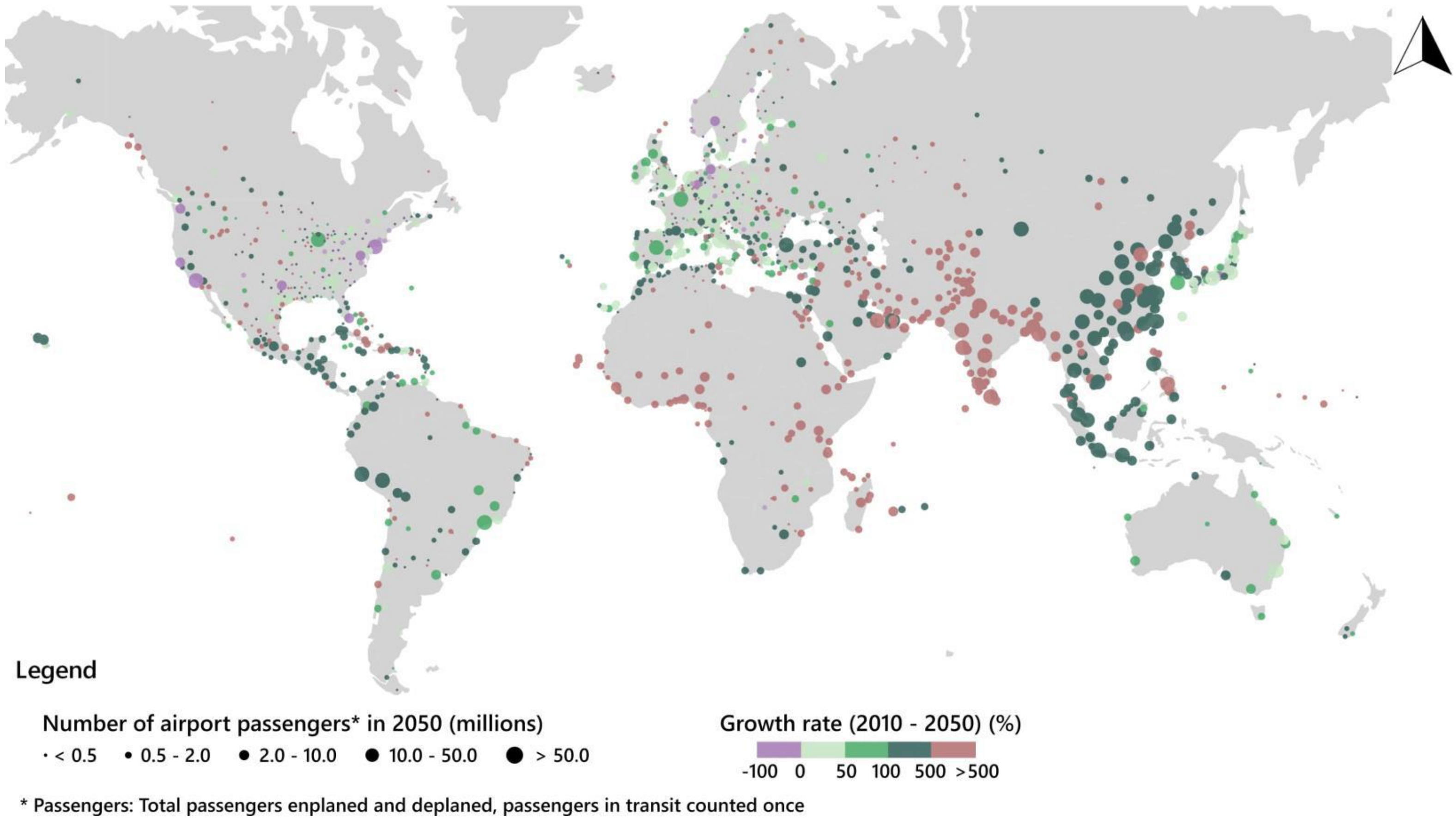
Million passengers

Region of origin	Region of destination	Number of passengers 2015	Number of passengers 2050	Absolute Growth 2015-50 (number of passengers)
China and India	Asia	39	382	344
Asia	China and India	40	376	336
OECD Pacific	China and India	44	247	203
China and India	OECD Pacific	44	247	203
Africa	Africa	33	180	146
Asia	Asia	78	214	136
Middle East	China and India	8	135	127
China and India	Middle East	8	135	127
China and India	China and India	37	157	120
Latin America	Latin America	24	90	66

Passenger numbers for airports follow a similar pattern. Asian (especially Indian) and African airports will see the biggest share of passenger growth. In China, some airports may eventually become the world's largest, with large cities like Beijing or Shanghai passing more than 500 million passengers annually. Latin American airports are also expected to grow significantly, mainly in large cities and tourism destinations such as the Caribbean islands and Peruvian cities.

Figure 4.2. Projected traffic growth at airports, 2015-50

Current ambition scenario, million passengers



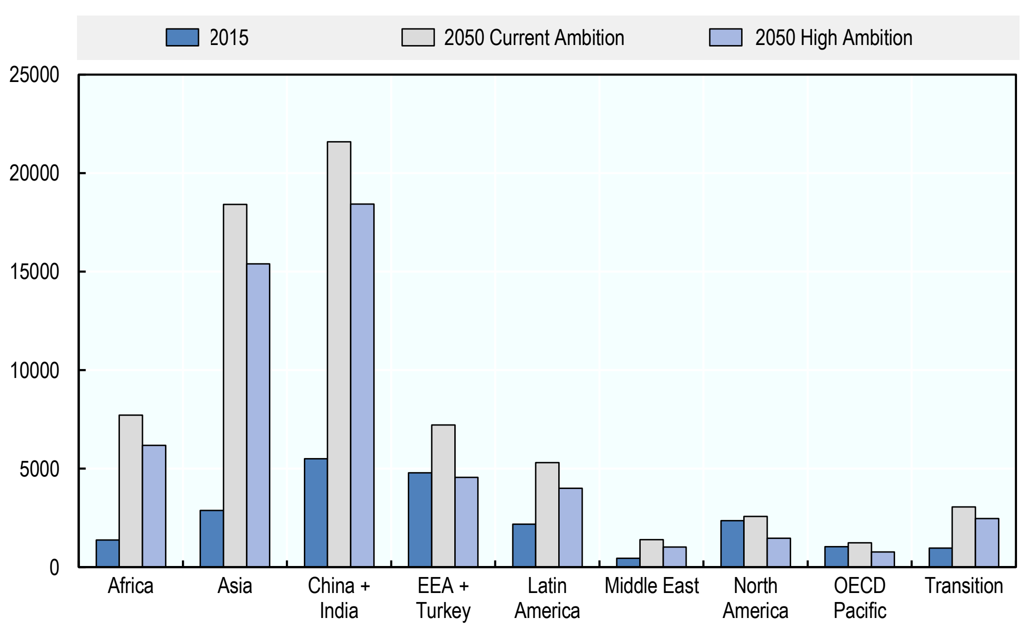
Passenger growth at European airports, on the other hand, could slow down compared to recent years. Some airports in northern European cities may even see a small decrease in passenger volumes. Reasons for the slow growth are demographic factors and the decreasing relevance of the hub-and-spoke model for intra-European air traffic. Airports in the United States could also face decreases traffic, mainly in the largest cities. A main factor here is the planned development of a high speed rail network in the US, which could absorb a significant share of domestic air traffic. A second factor is the greater prevalence of low-cost airlines which tend to avoid large airports and add direct connections between smaller airports.

A reduction of CO_2 emissions from non-urban passenger transport is possible

The high ambition scenario assumes a set of policies and technological developments that likely reduce transport CO_2 emissions to a greater extent than in the current ambition scenario. These policies make non-urban travel more costly (of USD 500 per tonne of CO_2 on average) than in the current ambition scenario. This affects predominantly fossil fuel-dependent aviation, fostering a faster development and uptake of alternative energy sources for aviation, such as synthetic fuels and electric planes, ultimately enabling carbon-neutral aviation at competitive cost. Surface modes see no additional investments; the high speed rail network remains the same as in the current ambitions scenario, with only planned lines being built. The uptake of electric vehicles is accelerated and vehicle occupancy increases Generally, the assumptions regarding technology in the high ambition scenario follow the International Energy Agency's 30@30 scenario (IEA, 2018[5]).

Figure 4.3. Projected demand growth for non-urban passenger transport by world region and scenario, 2050

Billion passenger-kilometres.



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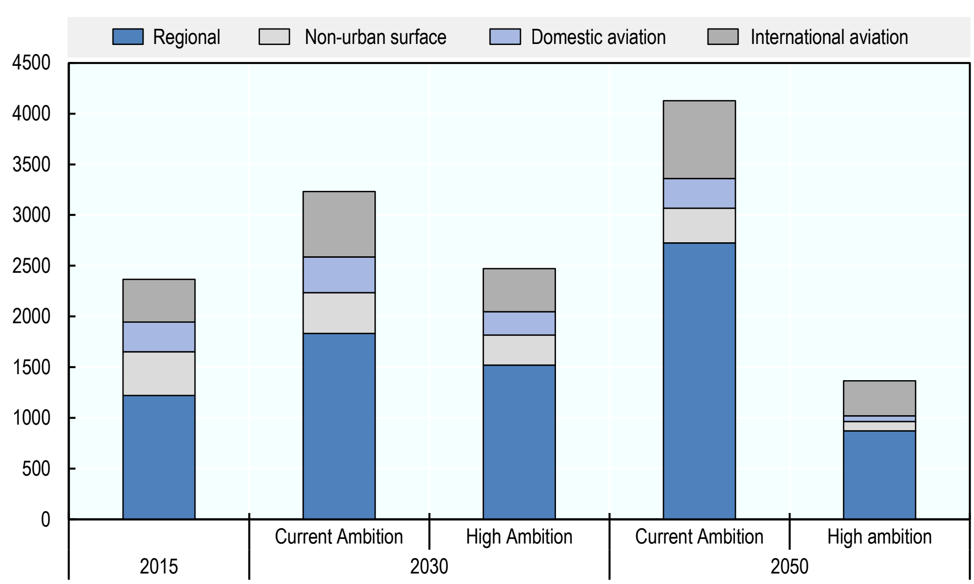
Demand for non-urban travel in the high ambition scenario is affected significantly by higher travel costs that result from the increased cost of emissions. Global non-urban travel globally will total 65 700 billion passenger-kilometres in 2050, a 22% reduction compared to the current ambition scenario. Higher fuel-related costs affect longer trips more strongly, as for these fuel is a bigger share of the total cost. Therefore the reduction is more pronounced for aviation, and especially international aviation which sees a 30% fall in p-km in 2050 compared to the current ambition scenario. All transport modes see a drop in total distance travelled, however.

As the cost of non-urban transport rises, demand for inter-urban travel is expected to decrease faster than demand for regional travel. Regional travel in the high ambition scenario in 2050 is estimated at 46 thousand billion passenger-kilometres, a 22% reduction compared to the current ambition scenario. Amongst regional travel, the biggest reduction occurs for car travel (25%). This is because regional travel consists mostly of travel that is essential for the livelihood of citizens residing outside of cities. Inter-urban travel, however, has a large tourism component which is not essential travel.

The more ambitious decarbonisation policies and the technology development assumptions of the high ambition scenario show a pathway for the decarbonisation of non-urban passenger transport. Despite a growth of non-urban travel by 150% under the high ambition scenario compared to 2015, CO_2 emissions in 2050 are only 58% of those of the base year 2015. This reduction is the result of developments in both OECD and non-OECD countries. In OECD countries, the vehicle fleet is almost entirely electrified by 2050 and transport demand decreases by 18%. As a result, CO_2 emissions form non-urban passenger transport reach only 14% of the 2015 level. In non-OECD countries, CO_2 emissions fall by 10% over the same period - despite an increase in non-urban travel demand of 257%. These figures do not include international travel, where CO_2 emissions fall by 25%, while travel in terms of passenger-kilometres increases 150%.

Figure 4.4. Projected CO_2 emissions from non-urban passenger transport by sector and scenario, 2030-50

Million tonnes of CO_2



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A possible solution for ending the dependency of aviation on fossil fuels is electric aviation, at least for short-haul flights. In the high ambition scenario, electric aircraft serve most short-haul routes up to 1 600 kilometres, so that these become true zero emission commercial air links, assuming that the electricity is generated from renewables. If synthetic aviation fuels also become available and cost competitive towards 2050, as the high ambition scenario assumes, the combined impact of these two developments would be impressive: Domestic aviation would produce only 20% of its 2015 CO_2 emissions by 2050, despite a projected demand increase of 78% over the same period, Similarly, international aviation would succeed in reducing its CO_2 emissions by 20% compared to 2015, despite a compounded annual growth rate of 2.7% that will take the sector 11 500 billion p-km travelled, up from 4 500 in 2015.

Box 4.2. Vehicle mass reduction: a possible transition to large-scale deployment of zero-emission vehicles

The average mass of passenger cars in the European Union has increased by around 40% over the past four decades. In 2015, a vehicle weighed on average 1 400 kg, compared to just under 1 000 kg in 1975. Additional mass consumes more energy and results in higher CO_2. Hence, a reduction in vehicle mass can contribute to reduce CO_2 emissions from vehicles.

A scenario for the impact of vehicle mass reductions developed by the International Transport Forum shows that CO_2 emissions from light duty vehicles in 2050 may be 21% lower than in 1990 in the baseline scenario, due to increased fuel efficiency combined with a moderate uptake of electric vehicles. A gradual reduction of vehicle mass to 1 000 kg for new passenger cars and 1 100 kg for new light commercial vehicles results in a near doubling of the CO_2 reduction compared to the baseline scenario: CO_2 emissions fall by 39% compared to 1990. Around 85% of these reductions would come from passenger cars.

However, these reductions would not be sufficient for reaching the European Union’s target of a 60% reduction in road transport CO_2 of these types of vehicles by 2050 compared to 1990 levels. The gap could be closed by a higher share of zero-emission passenger cars among new vehicles sold. If the share of zero-emission vehicles reached 64% for passenger cars and 68% for light commercial vehicles, EU emissions target could be attained.

Such mass reductions would entail a financial gain for consumers on top of the environmental benefits for society. Changes in fuelling and purchase costs alone would save consumers EUR 213 per tonne of CO_2 not emitted. For light commercial vehicles the picture is less favourable because reducing vehicle mass is more costly and purchasing them therefore more expensive. Here, owners pay EUR 977 for each tonne of CO_2 saved. Also the monetised environmental benefits would not outweigh the increased costs for the consumer.

Source: ITF (2017[9])

Ultra-high-speed rail

High speed rail has proven to be a flexible and attractive technology for users and has developed under different contexts and cultures. More than 43 000 kilometres of rail tracks were adapted to speeds of more than 250 km/h in 2018. High-speed rail systems were initially developed in Japan, with the Shinkansen in 1961, and then, starting from 1981, in Europe with the TGV in France. The first connections served large metropolitan areas within 200-400 km distance, i.e. routes where demand is high and high speed rail can be competitive with air transport.

Until 2010, the network was developing at a slow pace, with the great majority of the lines in Western Europe and Japan. Adoption has accelerated during the last decade. In particular, high-speed rail in China has developed rapidly over the past 15 years and covers 30 000 km of track today, 75% of the world total. Worldwide, 10 000 km of high speed rail lines are under construction, with an additional 40 000 km lines are planned or under discussion (UIC, 2018[10]).

Ultra-high speed (UHS) rail could be the next technological breakthrough, with the potential to disrupt current transport patterns. Whereas traditional high-speed rail systems use conventional wheel-to-steel technology with electric propulsion fuelled via overhead cables, UHS rail systems are based on electro-magnetic suspension. They could have operational speeds ranging in theory from 500 km/h to 1 200 km/h, compared to slightly above 300km/h for high speed rail. UHS trains are not new but there is a renewed interest in the topic, arguably because technological progress is foreseen in the near future. Two main types of UHS technologies exist today: Maglevs and Hyperloop.

Maglevs are trains operating solely via magnetic levitation. Maglev trains have been developed since the late 1960s in Germany and Japan with the aim of offering operational speeds of around 500 km/h. Although the technology has been used for a number of low-speed projects in the UK, Germany, Japan, and South Korea, high-speed Maglev systems have the most potential for changing current travel patterns in a significant way. Few high-speed Maglevs are currently in operation, but a large number of projects have been proposed in recent years. In China, a short high-speed Maglev line was opened in December 2003 between Shanghai Airport and the city's Pudong financial district. In Japan, a high-speed Maglev train between Tokyo and Osaka is slated to start operation in 2027. Further projects have been proposed throughout the world, including in India, China, and Iran.

Hyperloop systems are based on the concept of vacuum tube trains ("vactrains"): they use magnetic levitation technology in the same way as Maglev, but the train cars in these systems are sealed pods that travel enclosed in a reduced-pressure tube. This near-vacuum environment removes virtually all air drag and enables the vehicles to reach speeds of up to 1 200 km/h. An open-source conceptual model of the technology was published in 2013 in order to encourage technological advances and bring Hyperloop systems to market (Musk, 2013[11]).

A number of companies are now working on commercialising the Hyperloop technology and several prototypes are currently operational. The pods can be designed to carry passengers, vehicles, and freight, although preliminary study suggests that the Hyperloop's attractiveness for freight transport is limited (Taylor et al., 2016[12]). Feasibility studies and proposals have been submitted to construct Hyperloops around the world, including between San Francisco and Los Angeles, Chicago and Pittsburgh, Chicago and Seattle, Helsinki and Stockholm, Toronto and Montreal, Edinburgh and London, Glasgow and Liverpool, Mumbai and Pune, Shengaluru and Chennai, and Paris and Amsterdam.

What promotes the development of ultra-high-speed rail systems?

The uptake of ultra-high speed rail will mainly depend on its effective construction costs, the resulting fare levels, and the corresponding demand. As Maglevs and Hyperloops offer transport services which are in many aspects comparable to traditional rail – reliable trips between city centres with smooth boarding processes – final demand will depend mainly on fares. Ultra-high speed rail will be competitive if fares match users' willingness to pay for increased speed and if there is sufficient demand to cover upfront costs. The capital costs of UHS, and thus the fares required to cover them, are the key factors for their uptake.

With no large scale UHS service available today, the capital costs of these systems are largely uncertain. Multiple sources report variations in cost estimates differing by orders of magnitude (Table 4.3). The financial feasibility of the Hyperloop system in particular has received criticism see McLean and Nicolas (2016[13]) for a detailed costs analysis. While the original estimation for the Los Angeles–San Francisco project was USD 10 million per kilometre in 2013, subsequent commercial proposals put the figure at USD 40 million. Independent experts have also suggested the capital costs of the Hyperloop system (including vehicle costs) could exceed USD 75 million per km (for a review see Walker (2018[14])).

Furthermore, these estimates exclude cost of land acquisition as well as the various engineering and legal expenses required for large infrastructure projects. Also present may be the optimism bias seen in the costing of many large transport projects – an ex-post study of high speed rail projects in France, for instance, showed that actual construction costs were on average 20% higher than predicted (Meunier and Quinet, 2010[15]). Finally, ultra-high speed systems require relatively straight routes to avoid excessive lateral forces. The costs might thus slip to unstainable levels in regions with hilly topography, protected landscapes and high land values.

Table 4.3. Capital costs of high and ultra-high speed train systems

Type	Commercial speed (top/average, km/h)	Cost/km of track (USD million)
Hyperloop	1 000/750	10-75
Maglev	450/300	30-60
Conventional high speed trains	300/200	17-22

Note: Average speed calculated for origin-destination trip. Costs for Hyperloop and Maglev are estimates and exclude land acquisition. Costs for conventional high-speed trains are ex post and include land acquisition.
Source: Walker (2018[14]), for Hyperloop and Maglev; Cour des comptes (2014[16]), for Conventional high speed train.

Maglevs are already in operation and the technology's further development primarily depends on the financial model. As upfront costs are high, the long-term return on investment is uncertain and the level of risks is considerable, future Maglev infrastructure will likely not be funded from private funding sources in the near term. Government support will thus be essential, as it has been for high speed rail. As economies of scale should lower costs and demand for higher speed connections will probably increase, other financial models may well become viable in the long run.

Bringing Hyperloop systems into operation still requires technological advances. Significant technical issues need to be solved so that Hyperloop companies can meet their aim of having a fully operational system ready as soon as 2023. One of the steepest technological challenges is to maintain a vacuum in a tube several hundred kilometres long. The maximum speed Hyperloops have reached is slightly under 400 km/h, with a small-scale prototype on a test site. Traditional high speed trains have achieved test speeds of 570 km/h.

Questions have also been raised regarding the feasibility of Hyperloop's value proposition. The original Hyperloop proposal suggested that it could carry up to 3600 passengers per hour, with one 28-seater pod departing every 30 seconds. Several experts have argued that 80 seconds would be a more realistic departure frequency, given the minimum headway required for the vehicle to stop safely. This would dramatically reduce the capacity of the system, however. Other concerns raised focus on passengers' safety and comfort.

What impacts would ultra-high-speed rail systems have on passenger transport?

If implemented, UHS rail is likely to reshape transport patterns. Most adapted to provide trips in the 400 to 800 km range, UHS could potentially attract travellers now relying on short-haul aviation. The impact would thus be especially significant in regions with high levels of domestic aviation activity, such as the United States and China. They might also supersede traditional high speed rail services. Given that higher income levels are associated with higher values of travel time savings, new UHS rail projects could be favoured over new high speed rail projects, especially in countries such as the United States and the United Kingdom where extensive conventional high speed rail networks do not already exist.

Hyperloops and Maglevs could thus help to reduce congestion of airways and at airports. UHS rail would also contribute significantly to lower transport-related CO_2 emissions. Short-haul flights are particularly carbon-intensive, while electricity-powered UHS rail has a small carbon footprint, provided the source of electricity is sufficiently clean. That said, in terms of energy consumption the balance might not necessarily be positive for UHS. Maglevs require more energy per passenger-kilometre than traditional rail services, since air friction increases rapidly with speed, but do not offer significant energy savings compare to air transport. The Hyperloop system, on the other hand, consumes little energy as friction is limited in near vacuum. Its expected energy requirement could be 80% less than the one of an average US train. In principle this could be powered via solar panels mounted directly on the Hyperloop tubes (Taylor et al., 2016[12]).

UHS systems could also improve regional accessibility and stimulate regional economic development. This has arguably been a major impact of high speed rail, which can improve local business activity by changing the region's economic profile. High speed rail projects alter the relationship between accessibility and urban productivity. An important body of literature within the field of New Economic Geography has shown that the spatial concentration of economic activities entails productive advantages, the so called economies of agglomeration.

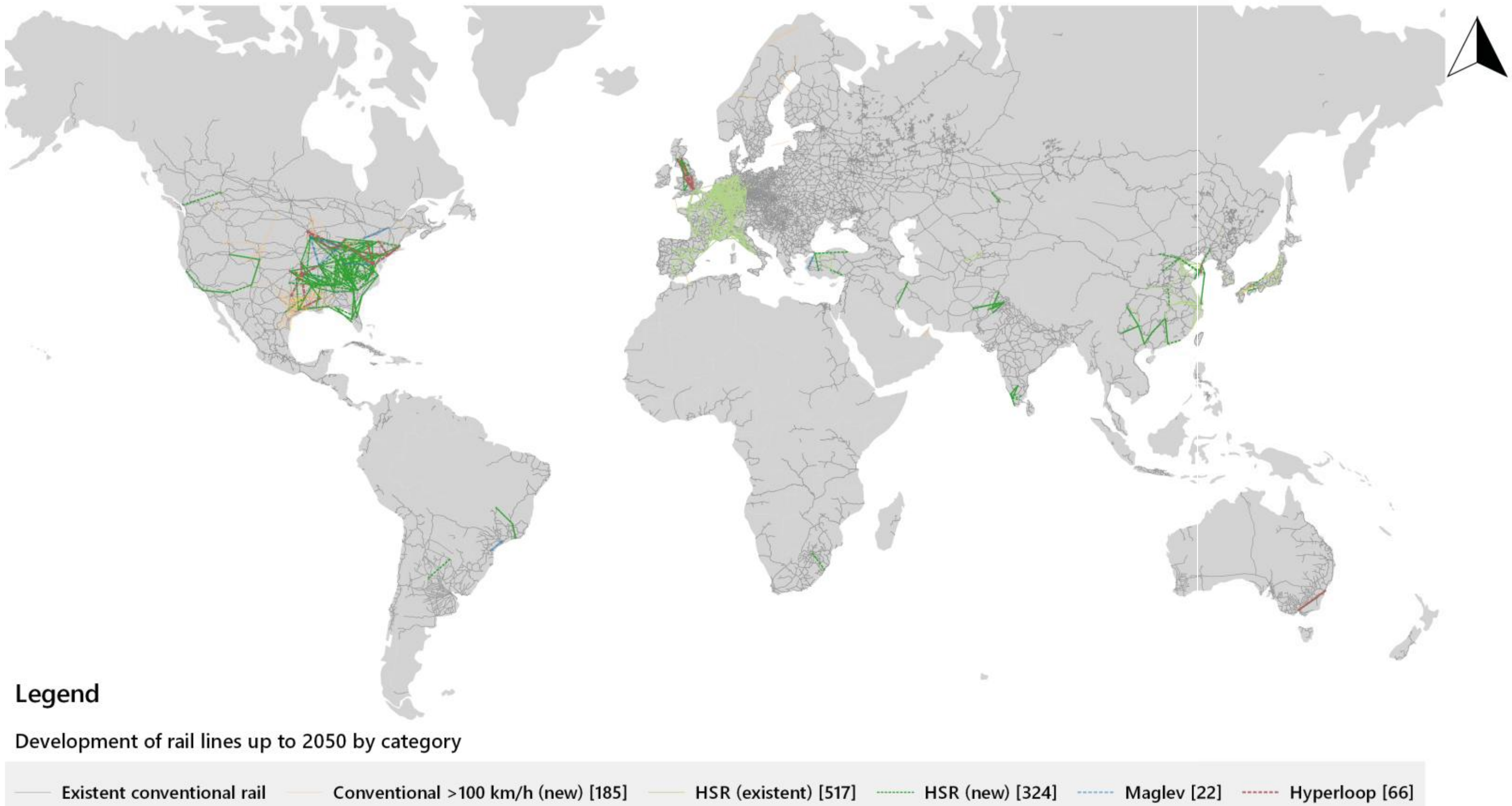
For example, projections see the planned high speed rail connection between London and northern England generating productivity increases worth between EUR 700 million and EUR 1.3 billion annually. Although it is difficult to assess to which extent, UHS will likely have similar effects with a much higher magnitude. They will fundamentally transform the economies they serve, inducing significant households and firms relocations. This is not to say that there are more benefits obtained from UHS rail than aviation. The potential UHS connections however would bring additional benefits as they would be added on top of air connections.

There is thus a case for further developing the traditional high speed rail network development. There are still around 200 links between city pairs for which a high speed rail link could be economically viable, according to an analysis by ITF that examined demand, costs and distance, among other factors. This untapped potential represents 50 000 km of tracks. Of these 75% would be in North America, reflecting the fact that high speed rail has been historically underdeveloped in this region.

This potential for development is already being acknowledged to some extent, with high speed rail receiving increased attention in the United States over the past decade. A High Speed Rail Strategic Plan produced by the US Federal Railroad Association identifies strategic corridors with 10 000 km of potential high speed track. California's high speed rail project is currently under construction and will run to a length of 1 200 km, assuming it is fully implemented.

The potential for high speed rail will become larger over time as transport demand grows and willingness to pay increases. Beyond the 50 000 kilometres of potential rail lines, an additional 25 000 km of tracks could be considered by 2050. At this time horizon, high speed rail is likely to also develop in middle income countries, especially in India, Latin America and, to a lesser extent, in North Africa. There are already signs of a growing interest for high speed rail in middle income countries. In Central Asia, Uzbekistan is successfully operating a 600 km network of high speed tracks allowing speeds of 250 km/h. India's first high-speed rail corridor between Mumbai and Ahmedabad started construction in 2017 and is slated to open by 2022. In North Africa, the Tangiers-Casablanca line opened in 2018, as the first phase of a planned 1 500 km high speed rail network in Morocco.

Figure 4.5. Projected development of rail lines worldwide to 2050



Note: HSR refers to high-speed rail

Developing high speed rail and UHS rail services are not the only possible path forward. Conventional and optimised rail services could serve as an alternative in many cases. Such services would not compete with aviation or high-speed rail in terms of travel time, but could be very competitive in terms of fare levels and thus able to attract a different user segment.

Simulation results

Investing into high speed rail can significantly increase rail traffic in terms of passenger-kilometres. Projections see an additional 170 billion rail passenger-kilometres to 2050 if all economically feasible high speed rail projects are implemented in the interim. This would represent a 14% increase in intercity rail traffic on 2015.

More than half of this increase would be in China and India. But the Americas would also see a notable increase in rail ridership, with an additional 35 billion passenger-kilometres in North America and 23 billion in Latin America. For city pairs located 400km to 800km apart, the market share of rail is expected to reach more than 50% by 2050. This is because the competiveness of high speed rail relatively to car and plane will increase with the expected increase in fuel prices and the progressive introduction of carbon pricing. Note that the total traffic expected on these new high speed rail systems is higher as a significant share of their patronage will come from traditional rail services. The total ridership of the new high speed rail services will amount to nearly 400 billion p-km in 2050 according to ITF estimates.

Yet globally this will have a minor impact on the total rail traffic. Currently rail traffic between large cities only represents 8% of total non-urban rail. Thus high speed rail has limited potential to increase significantly rail ridership. The projected additional 170 billion p-km only amounts for 1% of total rail ridership. Furthermore the impact of high speed rail projects on non-urban transport emissions is limited. The high speed rail projects would decrease CO_2 emissions by 5 million tonnes, which less than 1% of the domestic emissions of non-urban transport.

The prospects for UHS are more limited. Even if all the technological hurdles are passed and assuming there is no substantial subsidies, our estimates show a potential for 10 000 kilometres of UHS tracks, most of it located in Western Europe, North America and China. Although this implies that the UHS technologies as such could be viable, they will have a negligible impact on global transport pattern. UHS would generate an additional 40 billion p-km, with more than half of resulting for a modal shift from air transport.

Long-haul low-cost aviation

Civil aviation used to be a very strictly regulated and closed business sector dominated by network carriers. With increasing liberalisation of the aviation market, new players entered new business models started to emerge (Carmona Benitez and Lodewijks, 2008[17]; ITF, 2015[18]). The low-cost business model, pioneered in the United States by Southwest Airlines, employs point-to-point operations, shorter turn-around times, and service de-bundling among other elements (Doganis, 2005[19]; Doganis, 2010[20]). Different variations of that model exist (Alamdari and Fagan, 2017[21]) and have increasingly come to dominate short-haul aviation over the past 30 years. In 2017, low-cost airlines had a market share in excess of 50% of the seats offered in some regions: 57% in South Asia and 53% in South-East Asia. In Europe, a solid 37% of seats are booked with low-cost airlines and 32% in North America.

Importantly, airlines' business models have been blending for a while: Network carriers offer cheap de-bundled fare options, while low-cost carriers also sell up-market, almost business class-like options to their passengers. The main distinction can be drawn between low-cost airlines and full-service carriers. Full-service carriers have long relied on a strategy that involved big central hubs from which they service a multitude of destinations like spokes. The hub-and-spoke model enables them to gather enough demand to serve a large number of destinations in a cost-efficient way. This strategy is especially important for medium- and long-haul flights, because these require larger airplanes but are less in demand.

Low-cost airlines, on the other hand, mostly rely on direct point-to-point connections for their short-haul routes, which gives them a competitive advantage over full-service carriers. They have thus brought significant benefits to air travellers in the form of lower prices and new destinations, mostly on the short-haul sectors. It is therefore important to consider what would happen in long-haul markets if these would be entered by low-cost airlines on a large scale.

A number of network carrier, low-cost airlines, entrepreneurs and other players have attempted to transfer the low-cost model to the long-haul market (Morrell, 2008[22]). Most of these have failed, highlighting the differences that exist between short-haul and long-haul flights:

- A lack of origin-destination demand makes long-haul point-to-point operations less viable.
- Fuel costs are a much higher component of the total costs for long-haul operation and leave less room for cost reductions.
- Aircraft utilisation rates on long-haul routes are already high and reduce the potential to reduce costs through optimised utilisation.
- In-flight comfort and service is more important for passengers on long flights.
- Staff costs are significantly higher on long-haul routes.

Full-service carriers generate a large part of their profits on long-haul routes through business and first class passengers as well as cargo transport. Low-cost airlines cannot provide the schedule frequency, reliability and comfort that business passengers demand or offer the frequent flyer benefits that these often enjoy. Hardware aspects also complicate the entry of low-cost carriers into the long-haul market. Most use only a single type of aircraft, usually last-generation single-aisle planes with very high fuel efficiency. These are usually purchased in large numbers at a significant discount. However, the lower range of single-aisle airplanes limits their usability on long-haul routes, thus forcing low-cost newcomers to long-haul markets to buy or lease bigger aircraft and lose the cost advantages of a single-type, single-aisle fleet.

Nonetheless, a small number of low-cost carriers have succeeded in entering the long-haul market in the last few years, among them Air Asia X and Norwegian Long Haul.

Both airlines successfully serve multiple long-haul destinations, taking advantage of air liberalisation and flying with 5th and 6th freedom rights. Freedom rights give airlines the ability to fly to destinations beyond their native country; 5th and 6th freedom rights allow airlines to operate flights between two foreign countries under certain conditions. To a degree, they also use a hub-and-spoke strategy, as they use their parent companies, the traditional low-cost carriers AirAsia and Norwegian Air Shuttle, to deliver long-haul passengers to them. Using last-generation aircraft with significantly more fuel-efficient engines allows them to maintain a cost structure that is low enough to make operations economically viable. Nonetheless, their long-haul operations serve mostly big market pairs, and with a lower flight frequency than full-service carriers.[1]

What promotes the expansion of long-haul-low cost carriers?

Three main factors are behind the emergence of long-haul low-cost aviation. Firstly, the *liberalisation of aviation markets* makes it easier for new players to enter previously protected or closed markets in many world regions. Low-cost carriers in particular benefit from these regulatory changes, and many may soon offer cheaper flights also on long-haul routes where demand exists.

Secondly, the *technological evolution of aircraft* brings increased fuel efficiency and also allows new fuel mixes. Low-cost airlines rely on latest-generation planes to keep their costs low, therefor engineering advances in are more likely to translate into cost advantages and higher profit margins than for other airlines. Reductions in the fuel-related costs for longer flights or increased flight range of single-aisle aircraft put low-cost airlines in a good position to compete with full-service carriers on some long haul routes with high demand.

Thirdly, *increased demand for air travel* also leads to a growth of long-haul low-cost airlines. As more people want to go to specific destinations, their market becomes big enough to support new low-cost entrants. This is notably the case for the emerging aviation markets and of those in Asia in particular. Whether low-cost airlines generate new demand or absorb demand from full-service carriers has been much debated. The prevailing opinion holds that low-cost aviation does not add new demand, even if they need to absorb demand from full-service carriers in order to be viable (Gillen and Morrison, 2003[23]; Gillen and Lall, 2004[24]; de Wit and Zuidberg, 2012[25]). Therefore as demand is growing and is expected to continue growing, more routes will become viable for low-cost airlines.

Because of the characteristics of long-haul routes, the profit margin of low-cost airlines on these is smaller compared to short-haul routes. This makes operators very sensitive to oscillations in costs, and several initially successful low-cost airlines were forced out of business as fuel prices rose or the economy reduced the available budget of customers. The factors described above will likely make long-haul low-cost carriers more resilient.

Additional potential for long-haul low-cost airlines lies in absorbing market share from charter flights, similarly to what happened in the short-haul market (Rodríguez and O'Connell, 2018[26]). The characteristics of the typical charter passenger and the provided service are quite different from those of low-cost airlines, however, so that it is unlikely that low-cost carriers will completely replace long-haul charter flights. Nonetheless, this is another aviation market that long-haul low-cost carriers are likely to disrupt.

What are the impacts of long-haul low-cost aviation on air travel?

Low-cost airlines have had a huge impact on short-haul passenger aviation. Many network carriers initially ignored them, expecting them to fail. The aggressive stance of low-cost operators in combination with air liberalisation completely reshaped the aviation market. They development forced mergers between network carriers, pushed them to lower their prices and follow suit with other attributes of the low-cost model, such as service de-bundling.

Today, the entrance of low-cost carriers is disrupting the business model of network carriers on the long-haul routes. The low fares offered by budget operators will almost definitely absorb some cost-conscious customers from full-service carriers. Since the long-haul market is one of the most profitable sections for full-service carriers (Morrell, 2008[22]), full-service carriers are likely to compete aggressively; their larger profit margin might even allow them to sustain losses for a certain time. Overall, the arrival of low-cost airlines on the long-haul market will lower the cost of flying on these routes, thus increasing demand for these destinations, and ultimately traffic. Because all these additional trips will cover comparatively great distances, they will have a disproportionate impact on aviation's overall passenger-kilometres travelled and CO_2 emissions.

Currently, low-cost airlines offer medium- and long-haul flights mainly between Europe and North America and within East and Southeast Asia. Their market share in these regions was about 10% in 2018. Few low-cost flights exist for long- and ultra-long-haul routes, which points towards a maximum length for profitable low-cost services. Growth is more probable firstly on the shorter routes of the long-haul market, especially those that that can be covered with long-range single-aisle aircraft, and secondly in regions with a lot of untapped travel potential.

The first category includes route pairs such as North America and Europe, Europe and Asia, South and Central America to North America. The second category consists of South, Southeast and East Asia. These routes are also likely to first appear between cities that are already characterised by high demand. Routes that are today served by charter airlines are also likely to be see other operators offering low-cost flights for instance from Europe or North America to Central America or the Caribbean. This could be either new low-cost airlines entering that market or a full-service carrier flying a low-cost service.

The number of seats on medium- and long-haul flights provided by low-cost carriers will increase as aviation volumes continue to increase over the coming decades. Their market share will likely plateau at around 20% of the total aviation market, however, given the threshold conditions for profitable low-cost operations, the market characteristics and passenger preferences and priorities.

Continued liberalisation of aviation markets will increase the competition between network carriers and low-cost airlines on medium and long-haul routes. The result could be a further market consolidation that would reduce the number of big players, which could then compete more aggressively with low-cost carriers, either directly or with their own low-cost subsidiaries. Direct competition between the low-cost carriers will also become more intense as their market share grows.

Simulation results

A completely liberalised global aviation market in which low-cost carriers have entered most medium- and long-haul markets would be 9.5% bigger in terms of the number of air links in 2050 than in 2015 in the current ambition scenario. In terms or total passenger-kilometres, it would be 3.6% bigger. All of this growth would occur in international aviation, where the total passenger-kilometres increase by 5%. This section examines a scenario in which international air travel would reach 1 000 billion passenger-kilometres more in 2050 compared to the current ambition scenario.

Logically, the share of low-cost aviation in this scenario is higher. In the current ambition scenario, the share of low-cost airlines stays stable around 12-13% of the total aviation passenger-kilometres throughout the period 2015 to 2050. In a scenario in which low-cost carriers disrupt the aviation market, their share of total aviation p-km reaches 16% by 2050. This increase might not seem significant, but it represents a 20% market growth. The biggest market share increases for low-cost airlines in a disruption scenario are expected on routes between certain regions, particularly Middle East and transition countries. Nonetheless, the biggest absolute growth occurs in areas where low-cost carriers are already widespread, such as Europe and between Asia and China/India.

Alternative aviation fuels

Aviation has witnessed record growth in the past decade. It is currently responsible for 2-3% of manmade emissions, and its share is set to rise in the coming years as demand for both passenger and freight air transport is expected to grow further. Aviation is exclusively reliant on liquid hydrocarbons, so that demand for jet fuel will also continue to grow strongly. In 2015, jet fuel comprised 7.5% of global oil products (IEA, 2017[27]). Jet fuel is a product of petroleum refinement and blending, and its combustion produces CO_2, NOx and aerosols. The particulate matter produced through combustion of jet fuel is also responsible for increased cloudiness, which contribute to climate change (Lee et al., 2009[28]).

Most CO_2 emission reductions from aircraft derive from increased fuel efficiency of newer aircraft and the use of biofuels. Improvements in the fuel efficiency of narrow body aircraft may decrease the amount of fuel burned per revenue passenger-kilometre by about 2% per year until 2050 (Schäfer et al., 2016[29]) and as much as 3% if more ambitious measures are adopted (Dray et al., 2017[30]). With demand for passenger flights expected to grow by an average of 3.6% per year in terms of passenger-kilometres over the same period, efficiency gains alone will not be able to reduce aviation's CO_2 emissions below current levels but merely limit potential increase. Biofuels have long been considered to be a solution for decoupling the growth in air travel from the associated CO_2 emissions. However, concerns about negative side effects of biofuel generation, along with their high cost and limited availability, have prevented their more widespread uptake.

Electrification is playing a less significant role in aviation than in other transport modes, mainly because of the high energy requirements of air travel. Nevertheless, some potential for electrification in the aviation sector exists for short-haul flights, although it is conditional on sufficient technological progress (Schäfer et al., 2016[29]). Flights covering distances of less than 1 000 km account for 15% of all global revenue for passenger-kilometres and almost half of global departures. Electrifying these flights could eliminate around 40% of emissions associated with the take-off and landing of aircraft and reduce total commercial aircraft jet fuel use by 15% (Schäfer et al., 2016[29]). A reduction of other types of greenhouse gas emissions and noise pollution are additional benefits of electric aircraft.

Synthetic fuel also offers CO_2 mitigation potential. Synthetic fuel is created through chemical processes that combine carbon monoxide and hydrogen. Carbon monoxide can be extracted from multiple sources. A process known as direct air capture (DAC) is particularly promising in terms of it mitigation potential. In DAC, filters are used to capture CO_2 directly from the air, after which it is transformed into carbon monoxide that is used to create products such as gasoline and jet fuel. As the carbon content of synthetic fuel is extracted from the atmosphere, the emissions generated from the combustion of synthetic fuel do not increase the total amount of CO_2 in the atmosphere. Synthetic fuel also has a higher level of purity, which reduces the emission of other pollutants. A significant amount of energy is required to produce synthetic fuels, however.

What encourages the uptake of alternative energy sources in aviation?

The prospects for electric aircraft and synthetic aviation fuel depend heavily on the development of the respective technologies. The pace of development of battery technology in particular will play an important role in determining the prospects for electric aviation, as the weight and energetic capacity of electric batteries constitute a prominent barrier to their use in planes. Until constraints regarding power output, weight, and range can be eased, the role of electric planes will be limited.

Another major factor behind the extent and speed of electrification and synthetic fuel use in the sector will be cost, and their uptake will be strongly influenced by the evolution of oil and electricity prices. Commercial aviation costs are very sensitive to oil prices, and demand for aviation is also relatively sensitive to changes in price (Doganis, 2005[19]). Given current technology and energy prices, all-electric planes are more expensive than conventional aircraft (Schäfer et al., 2016[29]). Strong incentives favouring electric aviation will be needed to close the gap between the total costs of electric vs. conventional planes. The availability of cheap and renewable electricity will be a prerequisite for the scaling up of both technologies and will play an important role in determining the trajectory of their growth.

Increased prices of carbon in the future will translate into higher fares for conventionally-powered air travel, which could diminish demand. The price of flights powered by electricity and synthetic fuels would be relatively unaffected by a carbon tax. Thus, these technologies can play a role for decarbonising aviation as well as for ensuring mobility needs will continue to be met by aviation.

What are the impacts of alternative fuels on the aviation sector?

The electrification of short-haul flights and the use of synthetic fuels can significantly reduce the carbon intensity of air travel. As a matter of fact, Norway aims to become the first country where all short-haul flights are carried out with electric aircraft by 2040. Although both electrification and synthetic fuels emit no net tank-to-wheel emissions, the well-to-tank emissions generated by their production should also be considered when evaluating their mitigation potential. Fully decoupling aviation from fossil fuel consumption requires the use of renewably-generated electricity. If the decoupling can be achieved, this would facilitate significant growth in the demand for air travel, which could in turn result in a modal shift away from other inter-urban transport modes such as rail and road transport. A growing segment of the population avoids air travel for environmental reasons and emission-free aviation would allow them to consider using planes for their mobility needs.

A large share of the emissions from aviation is released in the upper atmosphere. There, the climate impacts of non-CO_2 pollutants can be significantly greater than the impact of their CO_2 emissions alone (Wickrama, Henderson and Vedantham, 1999[31]). Scientists debate the magnitude of this radiative forcing (Williams, Noland and Toumi, 2002[32]; Köhler et al., 2008[33]; Borken-Kleefeld, Berntsen and Fuglestvedt, 2010[34]). Electric planes and planes powered by synthetic fuels would significantly reduce radiative forcing effects because electric aviation does not produce any tank-to-wheel emissions and the combustion of synthetic fuel produces fewer non-CO_2 pollutants than conventional jet fuel.

Electric planes have the potential to disrupt the aviation market for short-haul flights up to 1 000 km. This segment accounts for 15% of aviation's revenue passenger-kilometres and about half of all take-offs and landings (Schäfer et al., 2018[35]). Given the weight, space and range limitations associated with currently foreseeable battery technologies, electrification is unlikely to extend beyond medium-sized planes and short-haul flights. Electric aircraft are also particularly likely to be used on routes for which other inter-urban surface modes require the construction of expensive infrastructure, for instance between islands or to connect remote locations. The uptake of electric aircraft is also more likely to occur first in countries where environmental concerns are more pronounced or where regulations for aviation emissions and noise pollution are more stringent.

The uptake of synthetic fuel in aviation will be heavily influenced by the evolution in the cost of conventional fuel (which may vary between countries or regions) and the costs involved in the production of synthetic fuel itself. In regions where electricity is relatively cheap and conventional oil relatively expensive, the cost basis of synthetic fuel will become more attractive than that of conventional jet fuel, and this will accelerate its uptake. Fuel taxes or carbon pricing could also contribute to increasing the cost advantage of synthetic fuel over conventional fuel.

Simulation results

The impact of alternative fuels on total aviation emissions does not depend solely on the development of the respective technologies and their cost. Switching to a new energy source will be mainly a cost decision, with few exceptions. Therefore the cost of conventional fuel and related policies will also affect the how fast and to what extent alternative energy sources will penetrate aviation.

In the setting of the current ambition scenario, conventional fuel will remain cheaper than alternative energy sources for most flights until 2045. Only in 2050 will electric aviation begin to be competitive and dominate some routes, covering 2% of all flights. In a disruptive alternative fuels scenario, the technological development of alternative energy sources happens more quickly and the related cost drop faster. With all else remaining equal, electric aviation replaces 42% of all flights in this disruption scenario. This share comprises most short-haul flights, since the assumed maximum range of electric planes is 1 600 km. The result would be drastically reduced emissions from short-haul aviation, particularly from domestic flights by 2050. Domestic aviation in the current ambition scenario would emit 293 million tonnes of CO_2 by that year, while it would be only

130 million tonnes of CO_2 in the *alternative fuels scenario*. International aviation will be less affected, as it includes mostly longer-distance flights. Nevertheless, emissions from international aviation will fall from 768 million tonnes of CO_2 in 2050 in the current ambition scenario to 700 million tonnes of CO_2 in the alternative fuels scenario.

The high ambition scenario provides a different policy and technology background than the current ambition scenario. Under high ambition policies, airplane efficiency increases compared to current ambitions and alternative fuel technology matures faster, albeit not as fast as in the disruptive scenario. More importantly, the carbon emission-related costs reach USD 500 by 2050. The combination of these elements fosters the development of carbon-free or zero net-carbon aviation. Thus, almost 37% of all flights would be in electric aircraft by 2050, while 2% would be powered by synthetic fuel. This would reduce CO_2 emissions, especially in domestic aviation, where they fall to 55 million tonnes of CO_2.by 2050, from 290 million tonnes in 2015. International aviation CO_2 emissions drop by 20% to 2050, reaching 343 million tonnes of CO_2, despite providing 2.7 more passenger-kilometres. Combined with the technological assumptions made in the high ambition scenario, the use of alternative aviation fuels on a large scale has even more ground-breaking results. In such circumstances, only 24% of all flights would use conventional fuel by 2050. All flights under 1 600 km would be carried out with electric planes and almost 50% of medium- and long-haul flights are powered by synthetic fuel. Aviation's CO_2 emissions in 2050 would consequently stand at 40% of the base year 2015, at 288 million tonnes of CO_2.

Three disruptive scenarios for non-urban passenger transport

This section analyses demand and emissions projections to 2050 in three scenarios that reflect more pronounced disruptive developments and mitigation measures in non-urban passenger transport. The potential impacts of these developments are uncertain and vary depending on demand, traveller's choices, new business models, the role of the service providers, as well as on other exogenous factors. Policy measures or their absence can strongly affect the ultimate impact of disruptive developments in the sector. Well-aligned policy measures can steer mobility changes towards more sustainable outcomes, such as vehicle sharing, which reduces congestion and emissions and increases connectivity and quality of service. To explore the scope of more extreme technological changes and the effect of non-urban related policy measures, three disruption scenarios were designed and tested. Table 4.4 summarises each of the tested scenarios.

The policy disruption scenario assumes that governments and international organisations in cooperation with private sector strongly promote decarbonisation in aviation and road transport. It implies three major changes. Firstly, carbon-related cost (in the form of carbon pricing or offsets) are charged at USD 1 000 per tonne of emitted CO_2. Secondly, favourable conditions for long-haul low-cost airlines and a halving of the cost of launching new long-haul air routes. Thirdly, an increase of shared non-urban transport and the creation of seamless multi-modal solutions for intercity passengers lead to one third of intercity trips will be shared trips. The pace at which technological changes integrate into mass transport solutions remains moderate in this scenario.

The technology disruption scenario assumes drastic technological progress in rail, road and aviation. Implementation of any new technologies is merely a question of economic feasibility. Policy makers make only moderate efforts to steer the changes. Specific assumptions include that the cost of alternative fuels in aviation will drop even faster than in the high ambition scenario relative to the cost of conventional fuel, the range of electric planes will increase to 2 000 km and that ultra-high speed rail systems will be introduced where economically feasible. In the road sector, the share of autonomous vehicles in non-urban traffic will reach 25% for cars and 12.5% for buses.

Table 4.4. Specification for three disruptive scenarios for non-urban transport

Mitigation Measures					
Assumptions	High ambition scenario	Policy disruption scenario	Technology disruption scenario	Full disruption scenario	Assumptions
	Carbon pricing	USD 500 per tonne	USD 1 000 per tonne	USD 500 per tonne	USD 1 000 per tonne
	Efficiency improvements and electric vehicles	Varies by region: 29.4-53.7% of cars and 10.5-56.5% of busses	Varies by region: 29.4-53.7% of cars and 10.5-56.5% of busses	Varies by region: 29.4-53.7% of cars and 10.5-56.5% of busses	Varies by region: 29.4-53.7% of cars and 10.5-56.5% of busses
Potentially disruptive developments					
Assumptions	High ambition scenario	Policy disruption scenario	Technology disruption scenario	Full disruption scenario	Assumptions
	Long-haul low-cost carriers	Very low share of low-cost airlines on long-haul flights (current trend)	Favourable conditions for long-haul low-cost airlines. Cost of creating a new route decreases by 50%	Favourable conditions for long-haul low-cost airlines	Favourable conditions for long-haul low-cost airlines. Cost of creating a new route decreases by 50%
	Energy innovations in aviation	Cost decreases three-fold by 2050 compared to conventional fuels. Range of electric planes reaches 1 600 km by 2050	Cost decreases three-fold by 2050 compared to conventional fuels. Range of electric planes reaches 1 600 km by 2050	Cost decreases four-fold by 2050 compared to conventional fuels. Range of electric planes reaches 2 000 km by 2050	Cost decreases four-fold by 2050 compared to conventional fuels. Range of electric planes reaches 2 000 km by 2050
	Autonomous vehicles	Varies by region: 0-2.5% of cars and 0-1.25% of busses	Varies by region: 0-2.5% of cars and 0-1.25% of busses	Varies by region: 10-25% of cars and 5-12.5% of busses	Varies by region: 10-25% of cars and 5-12.5% of busses
	Shared mobility	13.3-20% of all trips are shared	20.0 - 26.7% of all trips are shared	13.3-20% of all trips are shared	20.0 - 26.7% of all trips are shared
	Ultra-high-speed rail	current high speed rail projects or where they are already economically feasible	Current and feasible high speed rail projects plus Maglev	Current and feasible high speed rail projects plus Maglev and Hyperloop	Current and feasible high speed rail projects plus Maglev and Hyperloop

The full disruption scenario assumes that drastic technological changes occur *and* that policy-makers strongly promote decarbonisation in the aviation and road sector. It thus combines the impacts of both previous scenarios.

All three disruption scenarios assume that the electrification of vehicle fleets will reach the same level as in the high ambition scenario, i.e. in line with the EV30@30 scenario of the International Energy Agency (IEA, 2018[5]).

Each of the three disruption scenarios contains a combination of changes affecting travel costs, travel time and modes' convenience. These combinations have the potential to promote or supress demand. More specifically, the promotion of low-cost long-haul aviation, decrease in cost of electric vehicles and market penetration of autonomous vehicles, as well as possibility to share intercity trips, induces demand. Expansion of high-speed rail will likely bring additional demand as well, due to reduced travel time. Finally, it is assumed that vehicle load factors are inversely proportional to GDP growth; the corresponding elasticities used in the scenarios are based on Balcombe (2004[36]). This means that as GDP grows, passenger kilometres increase as well, all else being equal. On the other hand, carbon-related costs, which can be quite significant for all the disruption scenarios (Table 4.4) will raise travel costs and, therefore, affect the demand negatively.

The results of the disruptions scenario analysis show that sufficiently high carbon-related costs can lower overall travel demand and reduce CO_2 emissions, despite improved service and more convenience that tend to induce demand (Figure 4.4 and Figure 4.6). This finding is similar to the high ambition scenario, which leads to substantial CO_2 reduction compared with the current ambition scenario based on a medium level of carbon-related costs.

The policy-induced disruptions achieve the strongest CO_2 mitigation, while the technology disruption scenario displays the least improvements. The policy disruption scenario thus confirms the importance of action by governments and the private sector. This scenario results in a reduction of total non-urban transport CO_2 from 3.3 billion tonnes in the current ambition scenario to 2.05 billion tonnes in 2030 and from 4.1 to 0.94 billion tonnes in 2050.

The observed reduction trends for passenger-kilometres and CO_2 reductions are similar for regional and domestic surface modes, as well as for domestic and international aviation (Figure 4.4). The regional decomposition of all domestic urban travel shows that the disruption scenarios have the potential to reduce demand mostly in the OECD countries, and least of all in Asia (Figure 4.5). Carbon emission-related costs would reduce demand growth in every region of the world, but to a smaller degree in Asia.

The CO_2 emissions variation across the scenarios follows the changes in demand (Figure 4.4 and Figure 4.6). Carbon intensity does not vary significantly across the disruptive scenarios, decreasing over time for each mode (Table 4.5). Yet policy-related disruptions will have stronger effect than technological changes on the carbon intensity of most non-urban modes.

The carbon intensity of aviation decreases significantly in relation to other modes. This would make aviation a highly sustainable mode in the future, if the assumed shift to alternative fuels and electric planes takes place. While the cost reduction of the alternative aviation fuels and the increase of the range of electric planes mostly depend on technological advances and thus were assigned to the technology disruption scenario, governments and the private sector can adopt a variety of measures to make the corresponding emission reduction happen sooner rather than later. These include subsidies and tax incentives, stimulating research, and legal support (e.g. guidance on handling agreements for alternative fuels or aircraft conversions) to actors in the aviation sector shifting to alternative fuels.

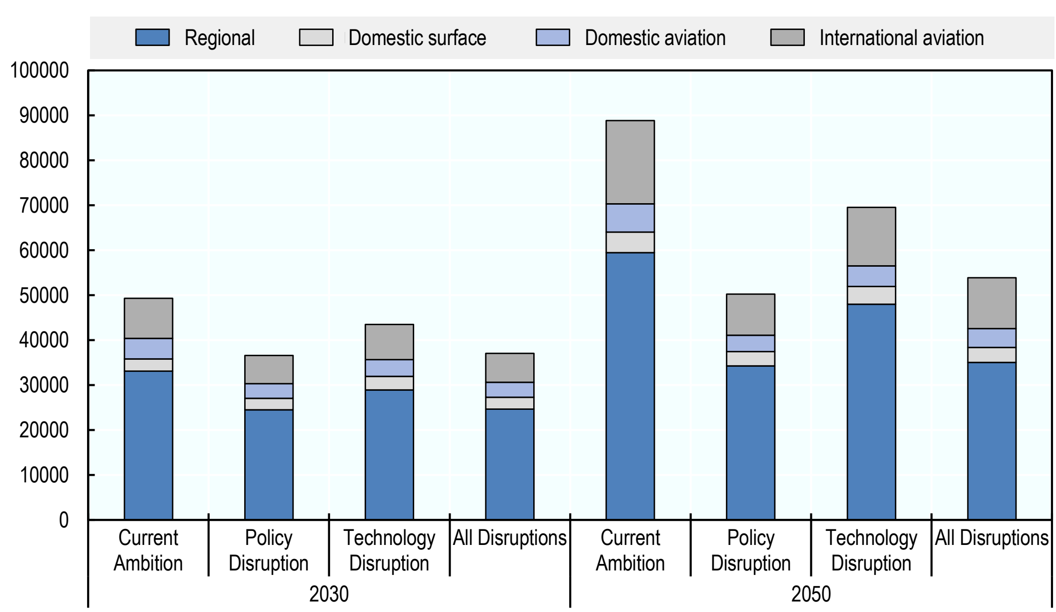
A comparison of the mode shares across the five scenarios shows that policies for non-urban travel should target the entire demand and carbon intensity, rather than focus on a significant shift towards less carbon-intensive modes. The non-urban mode shares (in terms of both passenger-kilometres and passengers numbers) are not especially sensitive to the changes in technology and policy considered, with a variance of 1-2% for all modes compared with the current ambition scenario. Rail gains modal share slightly in all disruptive scenarios. The small order of magnitude of this change shows that the expansion of ultra-high-speed rail is unlikely to attract many users from other modes. Nevertheless, the introduction of ultra-high-speed rail will improve user experiences and will further reduce the carbon intensity of rail transport.

Carbon-related costs strongly affect non-urban travel demand and its CO_2 emissions in all scenarios. Still, the results of the high ambition scenario and the technology disruption scenario demonstrate the effects of technological progress and some policy changes under the same level of carbon taxation. The comparison shows that fostering low-cost long-haul aviation could increase international aviation passenger-kilometres. In the technology disruption scenario, passenger-kilometres for international aviation grows by 14% from 215 to 2050. As mode shares stay almost identical, the additional travel distance stems from longer trips and not from an influx of passengers from other modes or a significant increase in the number of travellers.

The passenger-kilometres for railway trips also grow. As train services become faster, travellers are willing to travel farther. Besides that, the policy and technology scenarios show very similar demand across years and modes, implying that the technological disruptions do not have very strong effects on non-urban demand. On the contrary, the policy disruption scenario results in a more significant decrease in emissions, suggesting that policy measures will likely be more influential than technological changes in reducing emissions from non-urban passenger travel.

Figure 4.6. Transport demand by scenario and type

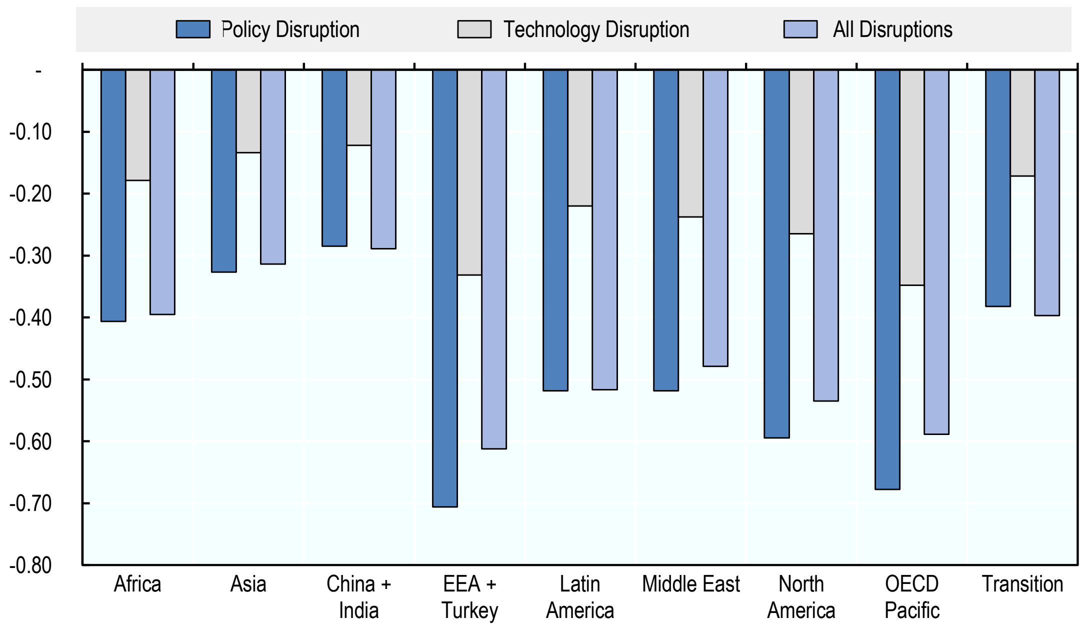
Billion passenger-kilometres



StatLink http://dx.doi.org/10.1787/888933972753

Figure 4.7. Projected domestic inter-urban transport demand by region and scenario in 2050

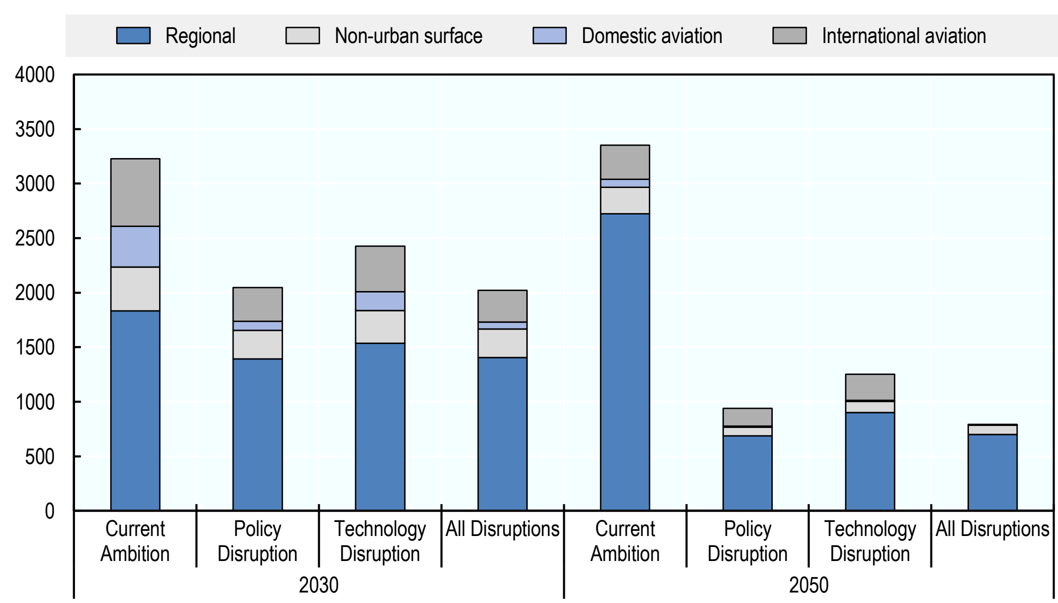
Percentage change in passenger-kilometres compared to the current ambition scenario



StatLink http://dx.doi.org/10.1787/888933972772

Figure 4.8. Projected non-urban transport CO_2 emissions by scenario and type, 2030-50

Million tonnes



StatLink http://dx.doi.org/10.1787/888933972791

Table 4.5. Carbon intensity evolution by mode

Grammes of CO_2 per kilometre

	2015	2030			2050		
	Baseline	Policy disruption	Technology disruption	All disruptions	Policy disruption	Technology disruption	All disruptions
Rail	7.15	2.18	2.09	2.08	0.16	0.16	0.16
Road	129	102	96.4	104	34.9	32.5	35.4
Bus	51.6	29.7	29.4	29.8	7.06	7.10	7.28
Domestic aviation	117	24.8	40.8	18.4	2.25	2.36	0.02
International aviation	94.0	49.5	53.6	45.8	17.6	17.8	0.68

Table 4.6. Projected non-urban transport demand by mode an scenario in 2050

'000 billion passenger-kilometre

	Current ambition scenario	High ambition scenario	Policy disruption scenario	Technology disruption scenario	Full disruption scenario
Rail	15.7	12.9	10.5	13.5	10.7
Road	36.0	27.8	20.0	29.0	20.6
Bus	11.3	9.1	7.0	9.4	7.1
Domestic aviation	5.5	4.4	3.7	4.6	3.9
International aviation	16.5	11.5	9.1	13.0	11.3

Notes

1 A significant body of literature examines the potential of expanding the low-cost model on the long-haul market. Some focus on specific markets and try to determine whether potential exists in the specific OD pairs: De Poret, O'Connell and Warnock-Smith (2015[37]) and Whyte and Lohmann (2015[40]). Others try to examine the business models and identify the elements that give an edge to successful attempts: Vidović, Štimac and Vince (2013[39]) and (Soyk, Ringbeck and Spinler (2017[38]).

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Chapter 5. Disruptions in freight transport

This chapter provides background on the transformation of freight transport and scopes the impacts of potential disruptions such as e-commerce, 3D printing, new international trade routes, autonomous trucks and high capacity vehicles. Also explored are scenarios that combine different disruptions, quantifying the impacts of more technology-oriented changes, logistic or exogenous transformation and all disruptions combined with high policy ambitions. The first section revisits the current ambition and high ambition scenarios for a more in-depth look at their freight-related features.

Strong growth expected in freight transport amid high uncertainty

Freight volumes will continue to grow strongly, with global freight demand projected to triple between 2015 and 2050. At the same time, freight transport and logistics are undergoing major transformations, and these will likely be even more disruptive in the future. Technology, business models, consumer behaviour, shifts in trade patterns and other factors all contribute to a changing transport landscape and how they play out can have a substantial impact on the projected growth.

Although unlikely, new opportunities for commercial shipping could open in light of the decrease of the extent of ice cover in the Artic sea, which would shorten distances considerably from Asia to both Europe and North America (ITF, 2018[1]). Large transcontinental infrastructure projects may establish alternative routes between major trade partners in East Asia and Europe, while also increasing access to markets in Central Asia and other regions including Africa. This can have an impact on port activity and the way surface transport infrastructure is used. Some parts of current road, rail and river networks could experience major reductions in traffic while others would see sharp increases.

E-commerce has been steadily growing and is predicted to increase further. Greater ease of purchase and returns can increase demand and foster a trend towards more individualised, small-scale deliveries, leading to more freight transport and increasing the share of relatively carbon-intensive modes, such as air and road.

Other disruptions can come from increased vehicle automation. The ability to decrease or totally remove labour costs and use vehicles in more flexible ways can significantly cut transport costs and revolutionise the freight transport market, not least by pushing up demand for road freight and shifting freight from rail and inland waterways onto roads.

Great uncertainty surrounds the extent to which re-shoring and 3D printing will dampen future growth of freight transport. If adopted extensively, both can affect the type of goods moved, decrease the distances between production and consumption centres and thus fundamentally alter today's long and complex supply chains. A significant decrease in the total value of internationally traded goods can greatly reduce sea and air transport volumes.

High capacity vehicles (HCV) that carry bigger loads than regular trucks are already in operation in some OECD countries, for instance in Finland and Australia. They could contribute to lowering emissions, limiting congestion and reducing overall transportation costs while increasing safety. But there are also caveats: Like other cost saving measures, HCVs could cause a rebound effect: If they cause a reverse modal shift from rail to road transport, the net impact on emissions will be negative above a certain threshold.

Zero or near zero-emissions propulsion for long-haul heavy freight trucks will not come into widespread use in the short to medium term. However, such solutions would need to be in general use by 2050 or earlier to reach the internationally agreed climate change targets. Decarbonising technologies for heavy-duty long-haulage currently foreseeable are the direct supply of electric energy to the vehicle ("electric roads"), hydrogen and possibly electric batteries. Their widespread adoption by 2050 could lead to a decrease of total freight related emissions, although this would also require zero-carbon generation of electric power and hydrogen.

Table 5.1. Current and high ambition scenario specifications for freight transport

Mitigation measures		
Assumption	Current ambition scenario	High ambition scenario
International trade, coal and oil consumption	Moderate reductions following the OECD ENV-Linkages model	Accelerated reductions. Coal and oil trade volumes decrease by 50% and 33%, respectively, by 2035
Logistics efficiency	Moderate efficiency improvements following the IEA new policies scenario	High efficiency improvements following the IEA EV30@30 scenario
Efficiency improvements and electric vehicles	Moderate efficiency improvements and electric vehicle uptake following the IEA new policies scenario	High efficiency improvements and electric vehicle uptake following the IEA EV30@30 scenario
Potentially disruptive developments		
Assumption	Current ambition scenario	High ambition scenario
E-commerce	Slight increase in urban freight demand (5% in more developed regions by 2050)	
3D printing	No change from current uptake	
New trade routes	Planned infrastructure capacity and connectivity improvements occur	
Energy transition for long-distance heavy freight	Following IEA new policies scenario	Energy transition for long-distance heavy freight
High capacity vehicles	5% increase in the uptake of high capacity vehicles for inter-urban road freight. HCV allow a 50% increase in truck loads and lower costs by 20% per tonne-kilometre	

Additional underlying assumptions	
GDP	Following ECO-OECD forecasts
Population	Following UN World Population Prospects
Transport network (Sea, Road, Rail, Inland waterways, Air)	Existing networks (2015). Planned ports expansion (increase in capacity) and some new road and rail links in Central Asia.
Transport Costs	Current generalised costs per mode, calibrated per country
Border-Crossing	Current assessment. Planned improvements in Central Asia.

Note: Assumptions regarding potentially disruptive developments correspond to non-disruptive levels in Table 5.7.
Source: Château, Dellink and Lanzi (2014[2]); IEA, (2018[3])

In order to estimate the impacts of each of these potential disruptions, individually as well as in combination, simulations for this *Transport Outlook* were carried out using an upgraded version of the ITF freight model that now integrates the (previously distinct) surface and international freight models. This brings greater consistency to the estimates produced, extends the ability to evaluate shifts in mode choice and allocates all freight volumes – domestic and international - to a multi-modal, routable and global network that covers sea, road, rail, air and inland waterways.

The network contains 7 707 "centroids", where consumption and production of goods takes place. Of these, 404 represent the origin and destination for international trade flows and 7 303 domestic flows. The 253 499 links contain information on capacity, travel time, distance, costs per tonne-kilometre (t-km) and border crossing times. The updated ITF freight model is also used to estimate the impact of policies under the current ambition and high ambition scenarios presented in Chapter 2. Table 5.1 summarises the assumptions for both scenarios regarding freight transport.

Elasticity of global trade to GDP has decreased since the 2008 financial crisis (WTO, 2018[4]). This has coincided with a rising number of trade disputes and increased protectionism (OECD, WTO and UNCTAD, 2018[5]). Should these persist, the impact could transform global supply chains and affect the volume of goods, the types of commodities, mode choice and distances travelled. This potential disruption should not be overlooked. Although it is not directly considered in this report, the simulation of the effects of 3D printing can provide some insights, as it is generally associated with re-shoring.

Disruptions represent qualitative transformations which can lead to paradigm shifts in manufacturing, transport, logistics and even land use. Their exact consequences are inherently uncertain, however. In this *Transport Outlook*, the potential impacts of these disruptions are quantified within a coherent and consistent modelling framework, reflecting the current knowledge on these topics and exploring the upper limits of these potential disruptions. Yet the results presented here are based on assumptions of future developments for which there is no historical precedent, and thus provide only a range for the potentially disruptive impacts on transport.

The mitigation potential of known freight transport policies and measures

Global freight transport accounts for 36% of the total transport CO_2 emissions today. Projections see its share of transport's carbon footprint increase to 48% by 2050 under the current ambition scenario. The figures show not only freight's current sizeable contribution towards CO_2 emissions, but underlines its increasing relevance towards the overall decarbonisation effort and the need to move decarbonising freight transport up on policy agendas.

The insufficient advances in reducing CO_2 emissions from freight transport are partly due to technical reasons that make it hard to decarbonise the sector. It will thus not be possible to decrease emissions from freight without added policy attention that support the deployment of both short-term measures that are relatively easy to adopt and more ambitious initiatives like wide-spread introduction of alternative fuels (ITF, 2018[6]; ITF, 2018[1]).

Even the deployment of ambitious policies will not suffice to reduce global CO_2 emissions below their 2015 level by the year 2050. Ambitious policy targets need to be associated with the deployment of a full array of logistical and technological measures combined with exogenous changes that may curb the rate of demand growth.

Important differences exist across regions and sectors. High ambition policies can decrease emissions for surface modes in Europe by 50% and by 41% in OECD countries to 2050. But in Asia and Africa CO_2 emissions will continue to increase, largely due to higher growth of transport activity and lower technological and logistical efficiency in several countries in these regions. Given the different geographic, economic, regulatory and infrastructure conditions, a set of regionally targeted freight decarbonisation strategies will be more suitable than a universal approach.

Carbon emissions from air and sea transport continue to grow to 2050 with currently implemented policies. This is because growing international trade increases demand for these modes more strongly. A second factor is that considerable progress in technical efficiency and carbon intensity reductions would be needed. Surface transport is easier to regulate by national governments or inter-regional associations of governments, whereas air and sea transport operate at a more transnational, even transcontinental, level. Although the International Maritime Organisation has announced absolute emission reduction targets, these can only be realised if far-going measures will be implemented, e.g. related to ship speed, energy efficiency and alternative fuels. Such a decarbonisation scenario is suggested in ITF (2018[1]).

If decarbonising efforts indeed increase their pace, in transport and sectors such as energy production decarbonise, the volumes of fossil fuels moved will also decrease sharply. The underlying international trade estimates in the current ambition scenario already include a decrease of the relative importance of fossil fuels compared to other types of commodities. The high ambition scenario assumes a more drastic decrease in volumes of coal and oil transported by 2035 (see Table 5.1).

A major difference between the current and high ambition scenarios are the respective assumptions about the efficiency of logistics and vehicle technology (e.g. see Figure 5.1 and Figure 5.2). The current ambition scenario assumes targets and policies announced by governments up to date following the IEA's new policies scenarios (NPS). The high ambition scenario, in contrast, assumes that 30% of new vehicles sold by 2030 are electric and that an extensive electrification of railways takes place.

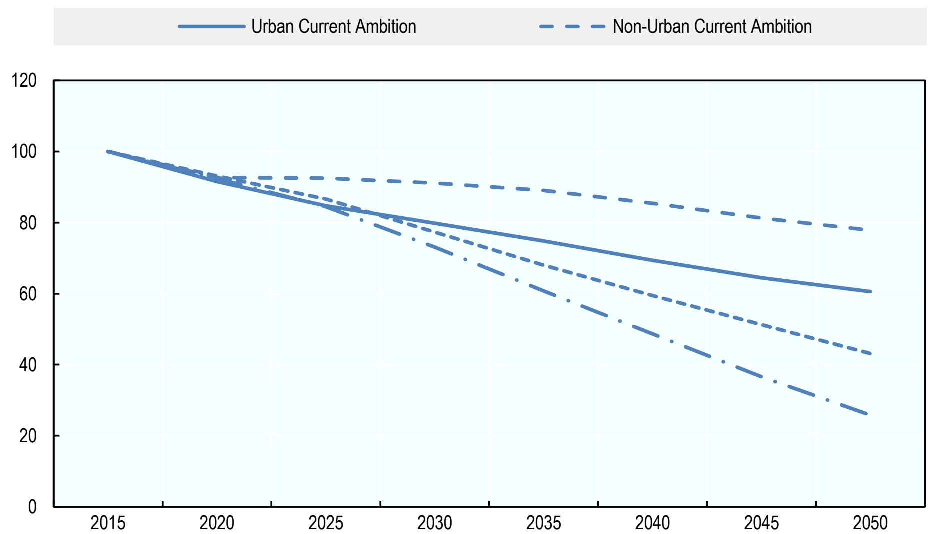
Scaling up decarbonisation measures for road freight transport that have already been tested and are comparatively easy to introduce is one of the most immediate actions required. For urban freight operations, alternative fuels already provide a viable commercial solution or shortly will. In both scenarios, more so on the high ambition, significant decreases in the carbon emissions for urban operations are assumed. Policy can foster measures such as the adoption of alternative fuels for urban logistics operations through pricing mechanisms and other incentives, stricter emission standards, zero emissions zones, recharging infrastructure and policies geared towards adoption of alternative fuels by large fleets.

Improving logistics practices also plays an important role in freight decarbonisation, with a potential to reduce emissions by as much as 30-50% (ITF, 2018[6]). However, there are only few case studies that substantiate costs and benefits. Anecdotal evidence exists of collaborative logistics schemes, but so far such practices have not been adopted at scale. Available data does not show a significant contribution of logistic solutions to CO_2 emissions reductions. Moreover, there is little data to properly assess the current situation and estimate the impacts that logistic solutions might have.

The difficulty to increase logistical efficiency in an urban environment is reflected in the actual decrease in average loads assumed in the current ambition scenario. This results in higher levels of congestion which, unlike emissions, cannot be offset by increased use of alternative fuels. Potential gains in logistic efficiency are set out in box 5.1.

Figure 5.1. Carbon intensity of urban and non-urban trucks in the current and high ambition scenarios

CO_2 per vehicle-kilometre, 2015=100



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Box 5.1. Optimised logistics for low-carbon freight transport

Logistic solutions have significant decarbonisation potential, even though more attention is paid to technological solutions for reducing CO_2 emissions from road freight transport (McKinnon, 2018[7]). Overall, more efficient freight operations could reduce CO_2 emissions from freight transport by between 45% and 67% (Holguín-Veras et al., 2016[8]). Logistical decarbonisation measures maximise the amount of freight tonnes transported per kilometre driven. They can include optimised routes, relaxed delivery windows, and shared assets between firms (ITF, 2018[6]).

Route optimisation alone could generate energy savings on the order of 1-5% (IEA, 2017[9]). Extending delivery windows can mitigate emissions by reducing vehicle speeds, consolidating trips and improving payload capacity use (McKinnon, 2016[10]). Energy savings from re-timing urban deliveries are likely to be around 5-10% (IEA, 2017[9]), although they are difficult to estimate. Re-timing deliveries can also help to reduce congestion, save time, reduce stress for staff, improve safety and enhance reliability.

A number of studies have found that narrow delivery windows can hinder efforts to increase capacity use (Route Monkey and WBCSD, 2016[11]; Transport & Mobility Leuven, 2017[12]; Sánchez-Díaz, Georén and Brolinson, 2017[13]). Re-timing deliveries goes against current market trends of increasingly on-demand shipping options, however. The cost savings involved in off-peak deliveries are attractive for freight operators, yet customers will require incentives to accept relaxed delivery windows. Local restrictions on off-hour deliveries in residential areas, often motivated by noise concerns, pose another obstacle to more flexible delivery windows. Incentives for freight operators to adopt low-noise technologies and vehicles could address this.

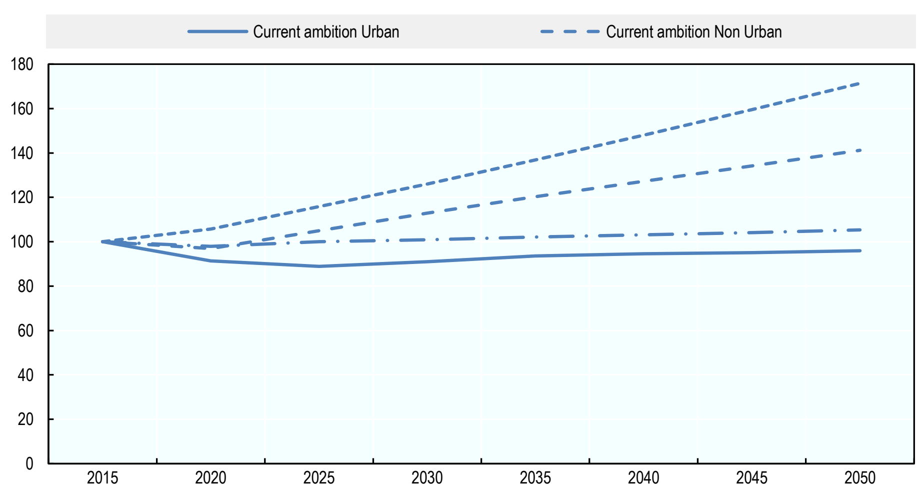
Supply chain collaboration can further decrease the energy consumption, costs and emissions of freight operations. It involves freight operators sharing vehicles, warehouses or workers to increase efficiency of deliveries. Digital tools can facilitate co-operation in an atomised sector. The impacts of collaboration and asset-sharing are arguably substantial, though difficult to quantify. Antitrust laws can hinder moves towards horizontal collaboration in logistics. Digital collaboration platforms, operated by neutral trusted third parties, offer a promising pathway to overcome these hurdles.

The physical internet could offer an operational revolution in the long run. The term stands for an open global logistics system in which asset-sharing and collaboration is coupled with modular standardised packaging units (Montreuil, 2011[14]). In the physical internet, standardised exchange protocols (e.g. with respect to parcel size and accompanying data) allow goods to be transported across modes on a common network in much the same way that information circulates on the digital internet, enabling large efficiency gains.

Challenges to implementing logistical decarbonisation measures include a lack of available data and research available regarding freight movements and their impacts, and the alignment of decarbonisation measure outcomes with the aims of profit-seeking firms and the broader market priorities related to maintaining and improving consumer services.

Figure 5.2. Average loads for urban and non-urban trucks in the current and high ambition scenarios

Tonnes per vehicle, 2015=100



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Box 5.2. Towards Road Freight Decarbonisation

The freight sector is an important factor for economic growth. Road freight is a flexible way to deliver goods, able to access most regions and is cost competitive with other modes. It will remain an irreplaceable transport mode, particularly for last-mile delivery. Road transport currently represents 18% of total freight activity and 57% of CO_2 emissions related to freight. Its share of transport sector emissions is projected to grow from 20% to 24% by 2050, barring disruptive innovation.

Within the framework of the Decarbonising Transport initiative led by the ITF, a workshop and an expert survey were conducted with the aim of identifying policies which are both cost-effective in mitigating the carbon footprint of road freight and improve the sector's operational efficiency. The main recommendations are summarized below:

- Broaden access to relevant data and improve their analytical uses for policies to decarbonise road freight transport
- Scale up tested and low-barrier decarbonisation measures for road freight transport
- Seek ways to overcome regulatory barriers to collaboration in the logistics sector
- Demonstrate the business case for investing in decarbonisation measures
- In the mid to long-term, mainstream the use of alternative fuels with ultra-low or zero CO_2 emissions for road freight transport
- Tailor decarbonising pathways to the economic and geographical realities of different country groups

Further insights can be found in ITF (2018[6])

Trucks that carry higher loads increase the efficiency of road freight operations. This does not always require high capacity vehicles (HCV). Renewing the fleet of trucks in developing countries with newer and larger vehicles (e.g. the standard heavy truck sizes in use in Europe or the United States) per se would have a significant impact.

The combined effect of improved technology and enhanced logistic efficiency, which is partly counteracted by a move towards lighter commodities with lower average loads, leads to a significant reduction of carbon intensity across all modes on the high ambition scenario. Surface modes in general and rail in particular achieve higher reductions than air and sea (see Table 5.2). In this chapter the disruptions in aviation technology presented in Chapter 4 for non-urban passenger transport were not considered. Though there are still efficiency gains.

Modal shift from road to less carbon intensive modes such as rail is another long-debated option to decarbonise freight. Indeed, road freight accounts for 18% of total freight volumes, but has the highest share of emissions emitting more than half of freight transport emissions. Rail transport, on the other hand, is already widely electrified in regions such as Europe or Japan and further electrification of railway lines is a relatively straightforward option to decarbonise freight transport.

This said, road freight transport offers a level of flexibility, accessibility and overall service level at competitive costs that make a pure modal shift difficult. In Europe, modal shift to rail has remained far below expectations, and there are several structural reasons for this (Crozet and Woodburn, 2014[15]). The European Union target, was to shift 30% of road freight over 300 km distance to rail and inland waterways by 2030, and 50% by 2050 (European Commission, 2011[16]).

Achieving the 2030 target would mean that the overall rail share would be close to 40% and road just above 50% according to Tavasszy and Meijeren (2011[17]). Yet it will be a challenge in itself for rail to keep its current mode share, given that demand for some core commodities currently moved by rail (i.e. heavy bulk materials such as coal and other fossil fuels) will probably decrease and more fuel-efficient trucks could narrow the gap in carbon intensity between long-haul road and rail freight. Though as seen in Table 5.2 in the high ambition scenario, presumably rail will decrease its already low carbon intensity more than any other mode.

In other regions, modal shift might be an option with greater potential than Europe. Rail becomes more attractive where longer distances need to be covered, the coastline is shorter, fewer ports are available, and transport corridors are more concentrated (e.g. in India, China or South Africa).

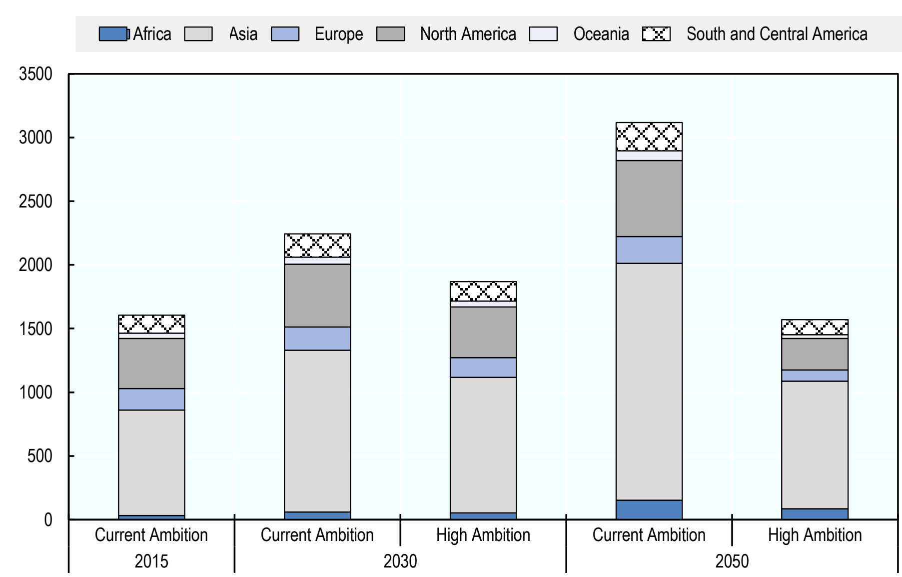
Table 5.2. Projected fall in freight transport carbon intensity, 2015 to 2030/2050

High ambition scenario, percentage decrease in tonnes of CO_2 emitted per tonne-kilometre

Year	Sea	Air	Non-urban road	Urban road	Rail	Inland waterways
2015-2030	-23	-29	-29	-27	-39	-37
2015-2030	-56	-51	-63	-76	-80	-68

Figure 5.3. Projected surface freight CO_2 emissions by region and scenario, 2030-50

Current and high ambition scenarios, million tonnes



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Implementing highly ambitious policies can significantly decrease emissions. Total freight transport CO_2 emissions still grow by 21% compared to 2015 in the high ambition scenario. This is almost only half the growth (45% less) seen in the current ambition scenario. Carbon emissions from surface freight transport (road, rail and inland waterways) decrease only slightly (by 2%) between 2015 and 2050. Regional differences are great, however: In Europe, freight emissions decline by nearly 50% and over 40% in OECD countries while there is a 20% increase in Asia and more than 150% in Africa.

Table 5.3. Change in freight volumes and CO_2 emissions in different scenarios

Percentage change compared to 2015

	2030		2050	
Scenarios	Tonne-kilometres	CO_2 emissions	Tonne-kilometres	CO_2 emissions
Current ambition	57	42	226	118
High ambition	51	18	216	21
E-commerce	61	45	238	127
3D printing	52	33	135	59
New trade routes	56	42	220	116
Energy transition for long distance heavy freight	57	31	228	84
Autonomous trucks	57	41	229	115
High capacity vehicles	57	37	225	110
Logistic	49	36	134	64
Technology	51	13	220	22
Full disruptions	49	13	133	-12

Sea and air freight volumes will see the largest increases by 2050. The associated CO_2 emissions mean that overall freight emissions will still increase, if no additional policy measures are implemented. Air and maritime transport are intrinsically international and subject to often complex international agreements, while surface modes fall mostly under national or regional regulation. It is also assumed that efficiency gains will be lower for air and sea transport than for the surface modes (see Table 5.2).

Box 5.3. Updates to the modelling framework for freight transport

The framework for modelling freight was considerably updated for this *Transport Outlook*. Most significantly, the ITF international freight model and the ITF surface freight model where integrated into a single model. Currently international and domestic flows are aligned to match the national tonne-km activity forecast calibrated from the data reported by countries. Both are matched using a calibration procedure that improves the route assignment but also assesses the domestic component of international freight and the share of urban freight. The international component still estimates activity for 19 commodities for all major transport modes and routes, while taking into account different transport and economic policy measures (e.g. the development of new infrastructure networks, or the alleviation of trade barriers). OECD trade projections are used to convert trade in value terms into freight volumes. The model consists of the following components: 1.Trade flow disaggregation model, 2.Value-to-weight model, 3.Mode choice model and 4. Equilibrium route choice model. The main changes are:

1. *A greater degree of disaggregation*: The model now has 404 centroids, with a greater degree of resolution in Central Asia and Africa.
2. *Incorporation of cost:* A cost function of each mode and country or region was integrated into the model for improve estimations for the base year (2015) but also the sensitiveness of the model to policies and disruption that may affect freight costs (either in mode choice and route choice).
3. *Route choice model:* The model now includes a route choice model in the assignment step that generates maritime movements, the potential ports and transhipment locations to connect each pair of centroids. The probability of each alternative is calculated as a cost function of handling and transport costs (fuel and time) of each connection. This is integrated in an equilibrium assignment procedure that updates the probabilities of each route choice for each iteration.
4. *Correct surface flows and modal split for countries:* The surface freight volumes for each country are estimated based on the economic forecast. These estimates are converted into local flows and are assigned to the freight network. Each country is represented by a set of surface freight centroid, which identifies all the GDP concentrations of the country located at least 100 km apart using a set coverage optimisation model. A shortest path assignment is estimated between national surface freight centroids and the estimated tonne-km is converted into tonnes travelling between centroids estimating an average distance and proportionally to the GDP concentration and population of each centroid (gravity based model). Modal split of internal flows within the countries are produced with a logit model choice model with the cost of each mode to perform a connection between centroids as utility function. The initial assignment produces a layer of traffic that constraints the equilibrium assignment to the network of international freight volumes.
5. *The ability to analyse the effect of policies or market exogenous factors that can be disruptive in the sector.* The model steps and countries specific cost functions were adapted to be able to accommodate disruptive changes (technological, demand and supply structure) on the freight sector and estimate the potential reaction of freight volumes and related externalities.

Figure 5.4. Projected freight volumes by mode, 2030-50

Current and high ambition scenarios, billion tonne-kilometres

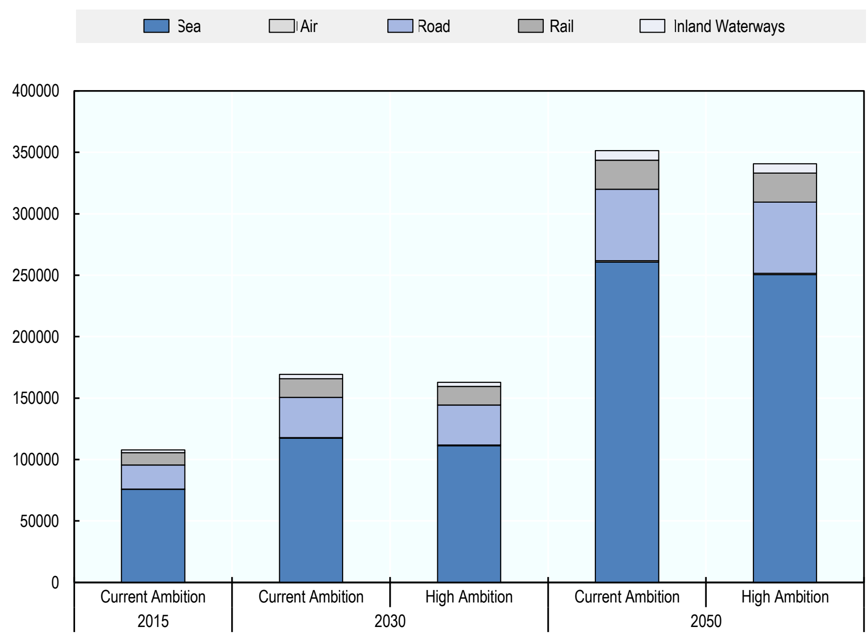

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Figure 5.5 and Figure 5.6 present modelled transport flows for 2015 and the activity at ports and airports.

Figure 5.5. Freight flows for sea, road, rail and inland waterways networks in 2015

Current ambition scenario, tonnes

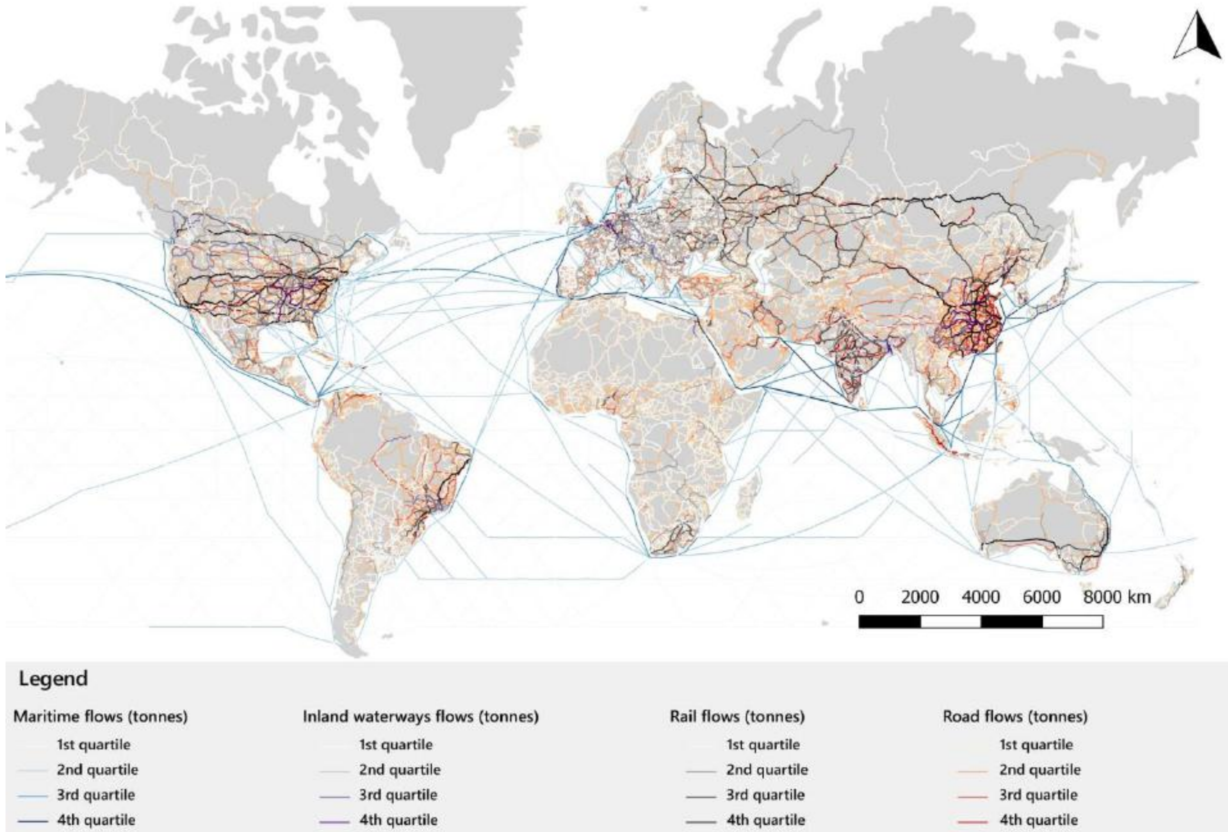
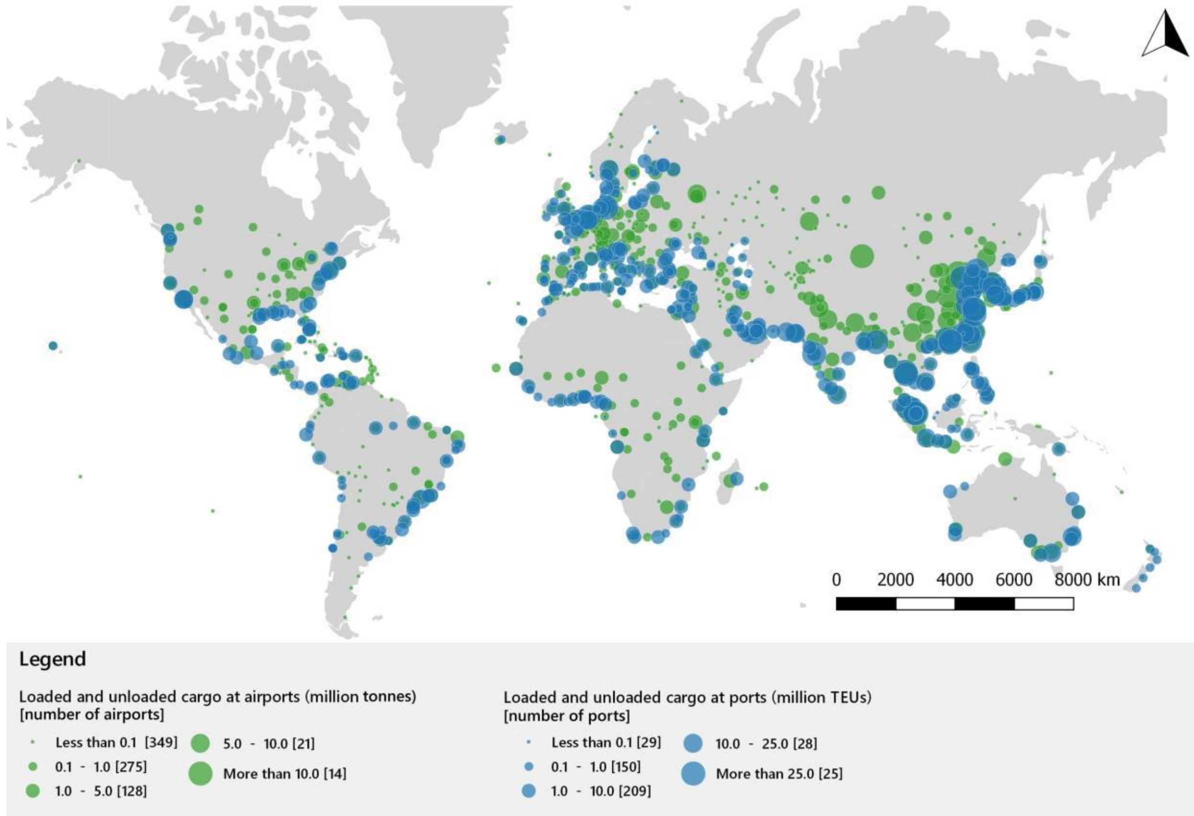


Figure 5.6. Volume of activity at ports and airports in 2015

Current ambition scenario, million tonnes and million TEUs



E-commerce

E-commerce can be defined as "the sale or purchase of goods or services, conducted over computer networks by methods specifically designed for the purpose of receiving or placing orders" (OECD, 2011[18]). Online sales occur either between businesses (B2B) or between businesses and consumers (B2C). This analysis focuses on B2C e-commerce activity; the fastest growing form of commerce and arguably the one with the greatest implications for transport, even if B2B transactions account for a greater total value.[1]

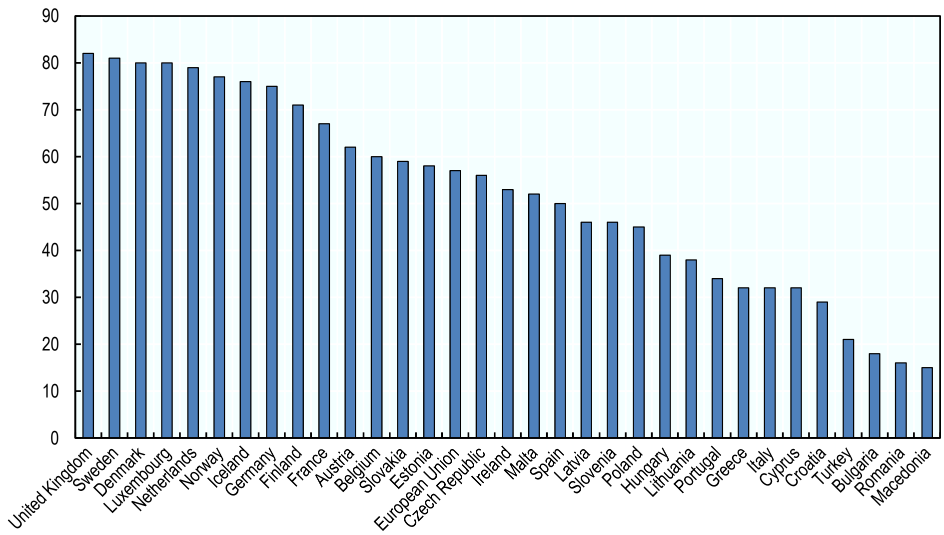
Initially operational in 1990, the World Wide Web was made freely available to the public in 1993. The rise of e-commerce began following the opening of the Web for commercial use in 1995. It was boosted by the introduction of internet browsers designed for non-technical users. By 1999, the global value of e-commerce sales had already reached USD 150 billion. It has continued to grow rapidly in the years since, powered by increasing internet connectivity, expanding global trade, and more sophisticated shipping technology. In 2017, the total value of global e-commerce sales was estimated at USD 2.3 trillion, an increase of 24.8% on the previous year (eMarketer, 2018[19]). E-commerce (both B2B and B2C) represented about 10% of global commerce in 2017.

Developing countries now account for the largest portion of new e-commerce, as its growth in developed countries is beginning to level off (UNCTAD, 2015[20]). Figure 5.7 shows the percentage of individuals who engaged in e-commerce activity across European countries in 2017 and Figure 5.8 shows steady growth in this rate in the European Union and selected developed countries.

The implications of the growing e-commerce industry for the transport sector were recognised as early as 2001 (OECD/ECMT, 2001[21]; OECD, 2003[22]). Almost twenty years later, the impact of e-commerce on transport patterns is undeniable. Nearly 80% of road freight experts surveyed by the ITF identified e-commerce as the trend most likely to be present in the sector by 2030 (ITF, 2018[6]). Respondents also indicated that they expect major e-commerce retailers to play an increasingly dominant role as logistics services providers in future years.

Figure 5.7. Share of population who made an online purchase in 2017 by country

Percentages

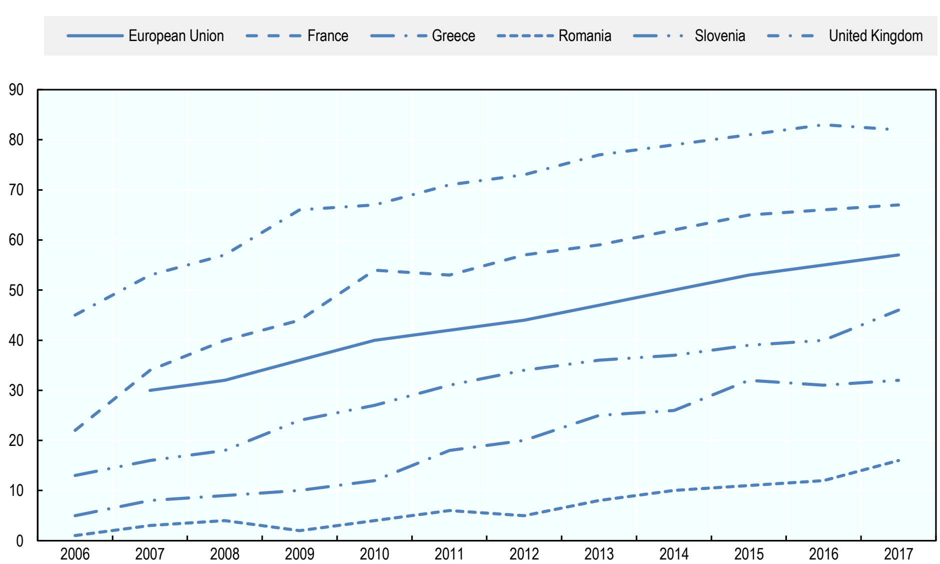


Note: Data unavailable for some countries.
Source: Eurostat (2019[23])

StatLink http://dx.doi.org/10.1787/888933972886

Figure 5.8. Evolution of the share of population who made an online purchase, 2006-17

Percentages



Note: EU data for 2006 is not available.
Source: Eurostat (2019[23])

StatLink http://dx.doi.org/10.1787/888933972905

What drives the development of e-commerce?

Online purchasing is associated with a number of socio-demographic characteristics, although the evidence is somewhat mixed. Some studies show that online purchasing activity is correlated with a high education level, an above average household income, as well as being female and Caucasians (Wang and Zhou, 2015[24]). Others found that men and younger people reported more online shopping activity than women and older citizens (Sener and Reeder, 2012[25]). Alternatively, other evidence suggests that there is greater interest in online purchasing among the elderly, disabled, two-worker households, and single parents (Mokhtarian, 2004[26]).

Given the great variety of goods and services available online, however, these mixed results are not surprising - the factors that affect the propensity and frequency of online purchasing activity are likely to vary according to what is being purchased. On the supply side, the determinants of a firm's decision to sell online can include its size, membership in an industry group, and having a consumer (vs. business) clientele (Coad and Duch-Brown, 2017[27]).

The most important reasons for buying online reported by European Union residents in the year 2000 were access to products not otherwise available in a consumer's area, price considerations, and the convenience of delivery options relative to in-store shopping. Factors that discouraged people from online shopping included concerns about after-sale service, the privacy of personal data, and delivery issues (European Commission, 2000[28]). Today, frequent online shoppers cite price and convenience as the most important reasons for shopping online. More recently, the most frequently cited reason for not shopping online more often is that customers enjoy having an in-store experience as well as being able to take the product home right away (Civic Consulting, 2011[29]), which indicates a continuing role for brick-and-mortar stores even as e-commerce continues to grow.

At a more aggregate scale, the pace of growth in e-commerce is also affected by business conditions (e.g. regulatory and tax environments) and technological developments. Goods delivery, payment systems, high-speed broadband availability, and retailer engagement have also been identified as factors explaining national differences in e-commerce activity (Civic Consulting, 2011[29]), with cultural factors and social norms also playing a role (Ben-Elia, Lyons and Mokhtarian, 2018[30]). This is particularly relevant in China, where online shopping has taken on a particular social significance and people now spend an average of 30 minutes a day shopping online (BCG, 2017[31]).

Concurrent trends in other domains are also expected to have a significant impact on e-commerce. The continued expansion of internet connectivity and the rise of mobile phone use across the globe are the most important. Transactions via mobile phones made up 58.9% of digital sales in 2017 and represent the fastest-growing purchase mode for e-sales (eMarketer, 2018[19]). Technological progress in areas such as the Internet of Things, autonomous vehicles and drones as well as artificial intelligence have also been highlighted as growth drivers for e-commerce (WEF, 2017[32]). In an "Internet of Things" world, for example, connected household devices could automatically re-order products when necessary. Advances in autonomous vehicles and drones could change transport patterns in the last mile of delivery, while artificial intelligence will, in turn, play an important role in the development of autonomous vehicles.

What are the implications of e-commerce for the transport sector?

The potential impacts of e-commerce on transport are highly complex. Identifying cause and effect in this domain is tricky and quantifying the precise impacts of e-commerce on transport demand and related CO_2 emissions fraught with difficulties. Their direction and magnitude will depend on factors such as urban density, mode shares and energy mix, for example, as well as on the nexus of physical, psychological and socio-demographic factors noted above (Cullinane, 2009[33]; Kos-Łabędowicz and Urbanek, 2017[34]; Mokhtarian, 2009[35]; van Loon et al., 2014[36]). Determining the ways in which e-commerce could reshape transport ultimately requires considering of how online shopping will change consumer behaviour, with regard to both travel behaviour as well as behaviour that has implications for freight demand. More on-demand deliveries within narrow time windows will reduce vehicle payloads, and customer returns of e-commerce products mean rising delivery vehicle-kilometres and lower average loads.

These behavioural changes can produce three different types of aggregate impacts (Mokhtarian, 2004[26]). Firstly, e-commerce can shift the way in which consumers purchase goods without changing the volume or total value of the goods they buy. Secondly, the generally lower prices made possible by online shopping in principle enable consumers to buy more goods without spending more than they used to. Thirdly, the option to purchase online may increase the total amount that people spend on goods by inducing new demand and increasing per capita consumption.

Empirical evidence suggests that overall greater e-commerce activity adds net transport demand. The proprietary nature of freight data make comprehensive analyses of the impact of e-commerce on freight demand difficult, a number of studies have nonetheless investigated this question, most found that e-commerce has a positive impact on freight demand, although the magnitude of this impact varies (Bonilla, 2016[37]; Mangiaracina et al., 2015[38]; Zanni and Bristow, 2010[39]). With respect to passenger demand, the evidence suggests that, while B2C e-commerce can have both complementary and substitutive effects on passenger travel demand, most of the literature points to a complementary effect, i.e. an increase in net passenger transport demand. Overall, thus, the dominant view in the research literature holds that e-commerce has a complementary impact on personal travel, rather than substitutive one (Commons, 2009[40]; Hauptbibliothek et al., 2015[41]; Mokhtarian, 2009[35]; Wang and Lo, 2007[42]).[1] The extent to which e-commerce changes current transport patterns will also depend on any mitigation measures put in place to accommodate this increased demand (see Box 5.2.)

E-commerce sales worldwide are projected to reach an average of 40% of the global market share in 2026, though this should vary by sector (WEF, 2017[32]). Governments worldwide have recognised the potential role of e-commerce in economic growth and have begun to actively promote it (UNCTAD, 2018[43]). The EU, for example, has launched initiatives to boost e-commerce, which including targets for the number of customers buying products online within and across member state borders (European Commission, 2013[44]; European Commission, 2016[45]). E-commerce will therefore almost certainly continue to put upward pressure on transport demand. The distribution of this demand over time, mode, demographic segment, and space, however, will depend on a variety of factors. The most disruptive effects are likely to be felt in the "last mile" due to increased volumes of activity and fragmentation of consignments.

E-commerce increases transport volumes and emissions

E-commerce is already changing logistics and is likely to play an increasingly dominant role in the way people obtain goods. This brings some decarbonising opportunities. But if unchecked, it is more likely to increase both emissions and congestion in cities. New business models offering free return of goods and requiring ever tighter delivery windows, constrain efforts to optimise operations and decrease the use of available capacity. Lower transport and transaction costs can lead to demand growth.

Policy can shape these developments. Promoting the use of collection points, off-peak deliveries and zero emission zoning will contribute to mitigating emissions. Other policies –e.g. distance-based charges - could nudge distribution operators to better use vehicle capacity and limit practices that foster less efficient transport and more congestion.

E-commerce is the only simulated freight disruption that actually drives up CO_2 emissions, with a 4% increase of total CO_2 emissions by 2050 compared to the current ambition scenario. This is directly related with increase in volume of activity (in t-km) that is associated with a strong growth of e-commerce.

Not all modes are affected in the same way, and different adoption rates are expected in different regions. The shares of different commodity types also changes over time. These factors combined help to explain why aviation movements increase more than any other mode, with road freight displaying the second largest increase. A disruptive impact of e-commerce will be particularly felt in urban operations and deliveries. These are the two most carbon intensive transport modes, so emissions are especially impacted by activity growth for these modes.

The increases seen in the emission projections do not account for likely losses of efficiency and average load for urban deliveries. There is no indisputable evidence for this, and some argue that increased economies of scale could even improve efficiency. But expert opinion tends towards assuming a negative impact on logistic efficiency, and hence more emissions and congestion. Thus, the negative impacts of e-commerce can potentially be even higher.

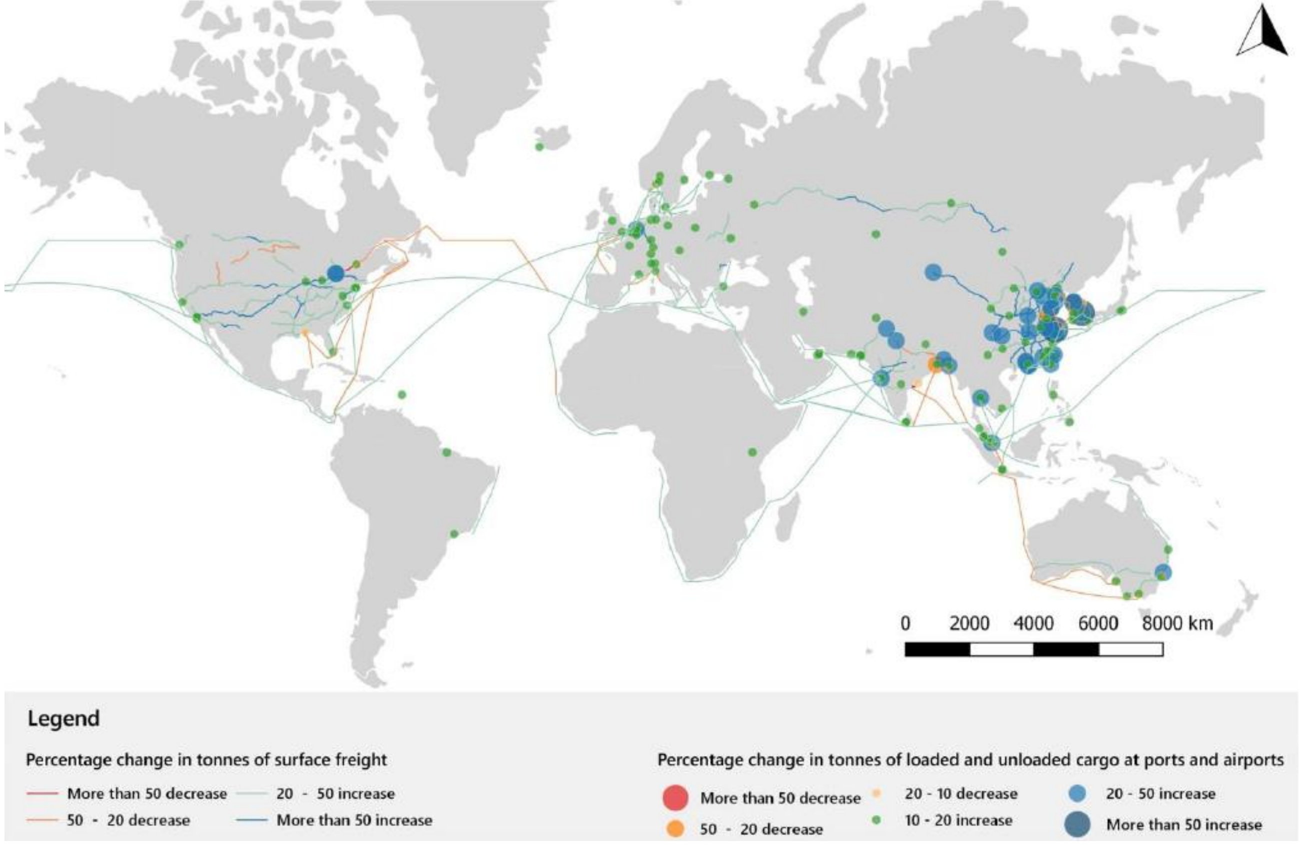
Table 5.4. Projected change in global freight volumes by mode in an e-commerce scenario, 2030 and 2050

Percentage change compared to current ambition scenario

Year	Sea	Air	Road	Rail	Inland waterways	Freight transport
2030	2	3	3	3	3	2
2050	3	11	6	4	2	4

Figure 5.9. Projected shifts of transport flows in the e-commerce scenario by 2050

Percentage change in tonnes compared to current ambition scenario



3D printing

Three-dimensional (3D) printing could dramatically disrupt the current goods manufacturing processes and accompanying global trade patterns if it is scaled up sufficiently. Traditional manufacturing processes typically assemble materials produced at different locations. In contrast, 3D printing uses an additive process whereby items are produced through the progressive addition of very small layers of material to create the final product.

The ability to produce any desired form or shape anywhere could in principle render superfluous the shipping of semi-finished products to assembly plants. Equally, small-scale 3D printing could enable households to print certain consumer goods at home, vitiating the need for shipment. While 3D printing is still an emerging technology today, it thus has the potential to fundamentally transform many production processes and disrupt the demand for freight transport (Campbell et al., 2011[46]).

To date, 3D printing is mainly used to produce prototypes and for niche applications. It is used in the manufacture of industrial tools and their parts (such as jigs and fixtures), geometrically complex and lightweight products in the aerospace industry, prototypes of parts and tools in the automotive industry, polymer-based consumer products as well as some medical and dental devices (ING, 2017[47]; McKinnon, 2011[48]).

3D printing is gradually assuming a greater role in the manufacture of industrial components and machine tools, however. The number of 3D printers sold worldwide doubled between 2005 and 2011, and in 2017 sales of industrial 3D printing systems costing more than USD 5 000 rose by 80% on the previous year alone (MGI, 2012[49]; Wohlers Associates, 2018[50]). Companies spent more than USD 6 billion on 3D printers and related services in 2016 (ING, 2017[47]; Wohlers Associates, 2018[50]).

What drives the uptake of 3D printing?

As the cost of 3D printers and related materials is falling, the industry is set to further expand rapidly. The future evolution of 3D printing technology will also depend on the pace of innovation, including improvements in quality, the ability to print larger-size items, and the speed of printing. The unit cost of 3D-printed items is currently high relative to goods that are batch-produced in traditional factories. 3D printers are also still limited in the range and size of products they can produce. These aspects and other technical difficulties related to current 3D printing technologies constitute the major barriers to massive consumer adoption of 3D printing in households (Mckinnon, 2016[51]; OECD, 2017[52]).

The drivers for a widespread uptake of 3D printing by businesses are generally the same as for households. The costs of purchasing and maintaining industrial 3D printers, their longevity, and the ease of integrating them into existing production processes determine their attractiveness for businesses. The costs of 3D printing materials and of transporting these materials will also play a role.

What are the potential impacts of 3D printing on transport?

The distinction between industrial and consumer 3D printing is important when considering the potential disruptive impact of 3D printing on transport. The possible impacts of additive manufacturing on trade and urban freight movements could be much more significant if home production became the norm for a broad range of household products (Mckinnon, 2016[51]). Despite the ostensible benefits that may accompany increased 3D printing activity, experts disagree on the direction and magnitude of net impacts (Boon and van Wee, 2018[53]).

The additive nature of 3D printing offers several advantages over the subtractive nature of conventional manufacturing. Additive manufacturing may require less material than traditional manufacturing, produce less waste, and enable the production of commodities closer to the site of their final use. 3D printing could therefore reduce freight transport demand by consolidating material transport and manufacturing activities. Indeed, freight transport activity could be significantly reduced by delivering only 3D printing materials to the point of production through simple supply chains rather than producing parts at different locations and combining them through complex multi-link supply chains (Mckinnon, 2016[51]). Instead of products delivered at home in separately delivered packages, the materials of these products could be held in stocks and delivered in bulk to the final destination. As a result, the tonne-kilometres of freight moved in urban areas could be substantially reduced.

Domestic 3D printing would use less material for most products than conventional factory assembly, and so could also reduce the need to transport goods between factories. In a world of mass 3D printing, freight traffic per value unit of consumption could drop sharply, leading to lower costs, congestion and CO_2 emissions. If 3D printing costs decreased significantly, this might lead to substantial re-shoring of manufacturing from countries with low labour costs in the Far East to Europe and North America (McKinnon, 2018[54]). Recent estimates suggest that 3D printing could make up as much as 50% of manufacturing activity, and that this would reduce world trade by 38% by 2040. According to these estimates, automotive, industrial machinery and consumer products would be the industries most affected and cross border trade in their commodities would decrease significantly (ING, 2017[47]).

Recent studies have challenged the view that 3D printing would shift manufacturing away from centralised factories to regional production sites or even consumer homes, however. They point out that 3D printers still mostly print parts rather than whole products, and that therefore most of the 3D products still need to be assembled in factories. Material for 3D printers will also still need to be shipped to factories or households.

Similarly, there are ground to question the argument that 3D printing can eliminate waste and avoid overproduction. It is true stocks of mass-produced goods are held in warehouses to be available in time for the predicted demand, while warehousing and the associated costs could in principle be avoided with 3D printing. However, unsold goods account only for 5% of most sectors' revenues on average and thus have only a marginal impact on global freight movements.

Two of the most-touted sustainability benefits of 3D printing may thus be overstated (OECD, 2017[52]). Transport constitutes only a small share of the total environmental impact of any product, and the potential of 3D printing for reducing the global carbon footprint of freight therefore seems to be rather limited. Existing 3D printing technologies in any case remain limited for now to the fabrication of parts rather than entire products, and these parts still require transport to their assembly points as well as shipping to their final destinations (OECD, 2017[52]).

Depending on the extent of its uptake, 3D printing has significant potential to impact on the manufacturing industry and on global supply chains. The adoption of 3D printing on an unforeseen scale would imply significant changes to logistics and manufacturing as production processes would shift from away from centralised factories and closer to consumers. Given the current state and uptake of 3D printing, however, it seems unrealistic that it will significantly disrupt transport and logistics systems. While it is likely that 3D printing will expand into more industries, its uptake will be limited not least by its inability to compete with conventional production methods that can produce larger numbers of a given product at lower costs. 3D printing will probably increase its role in prototype production and the manufacture of small items, but is less likely to reach the scale of mass manufacturing unless its costs decrease significantly (OECD, 2017[52]). In a survey of road freight experts, the majority of respondents expressed the view that 3D printing would have no significant impacts on the sector (ITF, 2018[6]).

In a scenario with relatively favourable yet not disruptive assumptions, 3D printing equipment would account for 8% of total manufacturing equipment in 2040 (Westerweel, Basten and Fransoo, 2018[55]). In the simulation for this *Transport Outlook,* we assumed the most disruptive assumptions that suggest a 38% decrease in global trade. Most of this projected change is driven by a reduction in movement of high-value commodities that are today produced in the Far East and then shipped to Europe and North America. To the extent that 3D-printed products could become important components in the construction of low-carbon technologies such as electric vehicles, 3D printing could conceivably contribute to lowering the cost of these technologies and thus accelerate their market penetration.

Mass adoption of 3D printing could significantly reduce international freight volumes

Growing freight demand is the number one driver for increased CO_2 emissions. These will not be reduced in a meaningful way unless demand growth stays substantially below current forecasts. Exogenous influences can have a significant impact on transport volumes and thus play a critical role in emissions reduction.

Among all simulated freight disruptions, 3D printing delivers the highest impacts on freight emissions, with a 27% decrease in freight CO_2 by 2050 compared to the current ambition scenario. The main reason is a 28% decrease in transport volumes, mostly in electronics and other manufactured goods. Air freight declines more sharply relative to other modes, since with more 3D printing lighter, high-value goods are manufactured closer to consumption centres. Average loads tend to be higher due to a relative increase of heavier goods being moved, resulting in and overall increase in energy efficiency of freight transport.

Massive changes in logistical global supply chains occur if the most disruptive assumptions of 3D printing that can be found in the literature are simulated. Figure 5.10 shows that the ports and airports most active in moving manufactured goods would suffer the greatest declines. Hence, East Asia would see the sharpest fall in freight flows. Globally there would be a significant decrease in congestion and excess capacity across transport networks and at their main nodes, at least compared to the current ambition scenario.

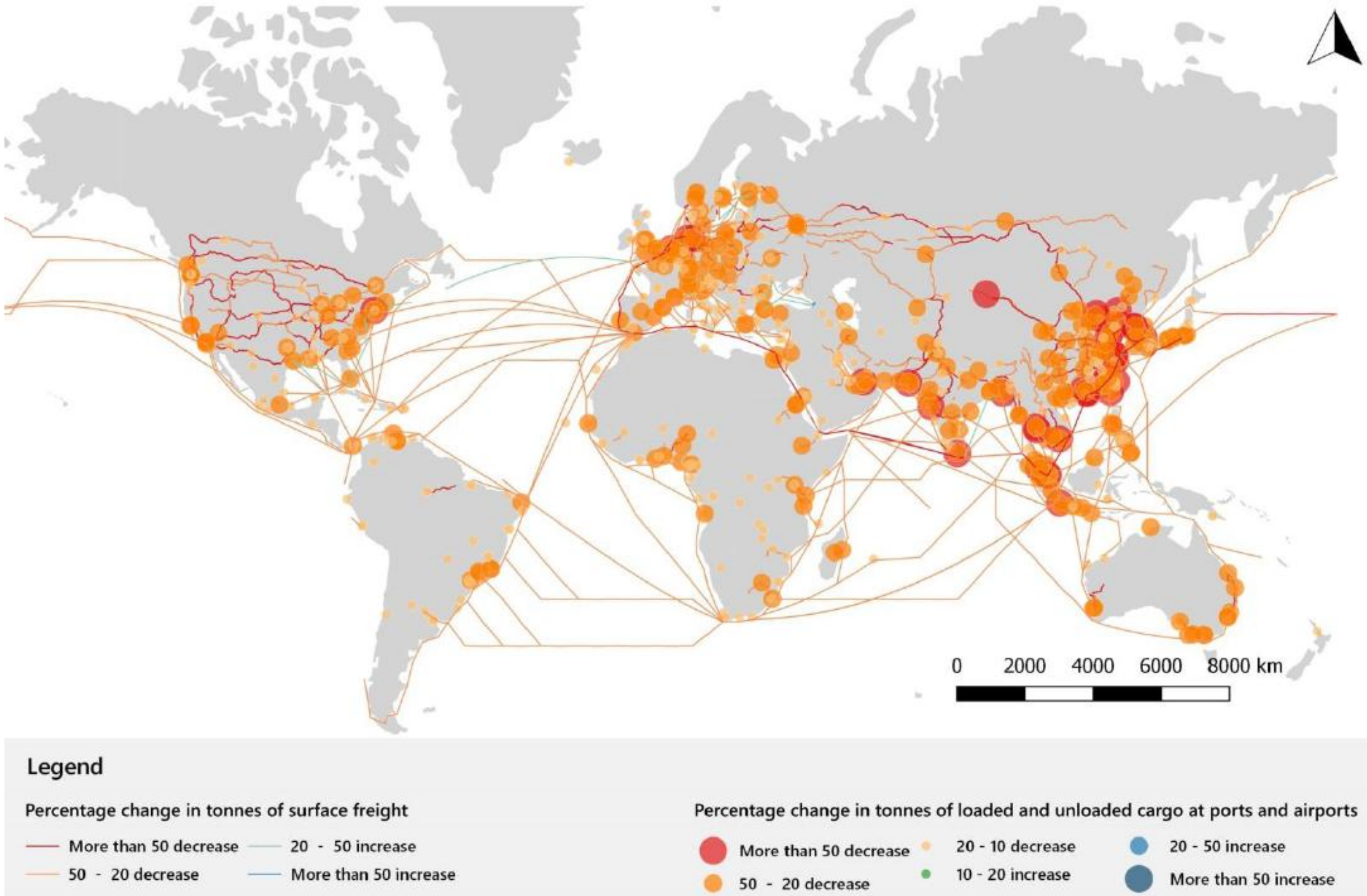
Table 5.5. Projected change in global freight volumes by mode in a 3D printing scenario, 2030 and 2050

Compared to current ambition scenario, percentages

Year	Sea	Air	Road	Rail	Inland waterways	Freight transport
2030	-3	-24	-4	-3	-4	-3
2050	-32	-56	-15	-10	-26	-28

Figure 5.10. Projected shifts of transport flows in the 3D printing scenario by 2050

Percentage change in tonnes compared to current ambition scenario



New international trade routes

Shifts in international trade routes could considerably alter freight transport demand in the coming years. These shifts could result from new and improved freight networks in Eurasia and Africa and from new maritime routes opening up in Arctic waters. Surface freight networks in North America are not expected to change significantly in the coming years. In South America, investment in infrastructure as a percentage of GDP remains low, and a corruption scandal involving the region's largest construction company has halted many projects. Significant improvements in infrastructure in South America are therefore likely to be slow in the near future.

New canals could also provide alternative maritime routes that would shorten existing trade routes. The Kra Canal across the Malayan peninsula would cut the distance for oil from the Middle East to reach China and Japan by 1 200 km, the equivalent of two to three days.[1] The proposed Nicaragua Canal across the Central American isthmus could provide an alternative to the Panama Canal that would be better able to accommodate the biggest ships. Both projects seem unlikely to materialise in the near future, however.

Regular train connections already carry some freight between Europe and China via the Russian Federation. Three main railway corridors have been identified that span the Eurasian continent to connect China, Central Asia, Europe, South East Asia and South Asia. Among these corridors, the northern route – using the Trans-Siberian railways or Kazakhstan's rail system – is currently the only route with stable and reliable transport services and infrastructure (UIC, 2017[56]). It consequently has the highest traffic volumes.

Only about 1% of trade between Europe and Asia is transported via rail, while more than 90% is transported via ships (UIC, 2017[56]). But rail freight flows between East Asia and the European Union have increased significantly in recent years, from 25 000 Twenty-foot Equivalent Units (TEU) in 2014 to 145 000 TEU in 2016, which is still significantly less than the containers transported by sea between Asia and Europe. Finally, Azerbaijan, Kazakhstan, Georgia and Turkey have agreed to construct the Trans-Caspian International Transport Route (TITR) as part an intermodal East-West transport infrastructure initiative.

In Africa, investment in infrastructure projects is accelerating quickly due to the recognition of their importance for the development of the continent (AfDB/OECD/UNDP, 2017[57]). A number of initiatives seek to increase regional integration in Africa, including the Boosting Intra-Africa Trade action plan of the African Union and the Trade Facilitation Agreement of the World Trade Organisation (WTO). Road, rail, and maritime transport have been targeted for improvement. Freight connectivity on the continent is currently highest in South Africa. Greater connectivity between South Africa and eastern Africa is expected to be developed by 2030, and between eastern and western Africa by 2040.

With regard to new maritime routes in the Arctic, the Northeast and Northwest Passages already experience some use during the ice-free summer period. The Transpolar Sea

Route is navigable throughout the year, but only with powerful icebreakers. Increasing melting ice cover over the Arctic Sea has created new possibilities for commercial shipping. The Northern Sea Route, for example, is predicted to be ice-free on a seasonal basis sometime between 2040 and 2050 (Smith and Stephenson, 2013[58]). The Russian Federal Agency for Maritime and River Transport has reported a volume of 9.7 million tonnes of goods shipped on the Northern Sea Route in 2017 (Marine Insight, 2018[59]), compared to 2 million tonnes throughout most of the first decade of the 2000s. Although, this represents an infinitesimal amount of intercontinental trade and the main maritime trade routes.

What could drive changes in international trade routes?

Investment in infrastructure is the most significant driver of the development of new freight routes in Eurasia and Africa. In China, the major expansion of rail connectivity with Europe has gathered political momentum and considerable political will exists to increase network capacity. Although transport by rail is five times more expensive than transport by sea, it is about 1.7 times faster. This makes rail an attractive mode for transporting highly time-sensitive goods, such as fashion goods, electronics, car parts and perishables including food. The significant increase in rail freight flows between East Asia and the EU in recent years can be attributed to reductions in transit times and an increase in reliability, which are in turn a result of better infrastructure as well as more efficient handling, customs and border-crossing processes.

In Africa, regional integration has become a priority and investment in infrastructure projects is increasing. In 2015, member states of the Common Market for the Eastern and Southern Africa, the Eastern African Community and the Southern Africa Development Community signed a tripartite trade agreement to enhance market integration, infrastructure development and industrialisation. Under the African Union's Programme for Infrastructure Development in Africa, many rail, road, and maritime investment projects are planned or under way.

In the Arctic, maritime operators who are considering using the Northern Sea Route face a trade-off between the gains from shorter distance and the higher costs of Arctic shipping. Apart from meteorological conditions and heightened safety concerns in Arctic waters, operators face logistical barriers due to scarce infrastructure, strict certification requirements, and tight environmental regulations, e.g. voyage planning restrictions aiming to protect marine ecosystems (USCG, 2017[60]). The Polar Code sets strict standards including on ship design, crew training, fuel tank characteristics, or sewage discharge. Even more stringent environmental regulations could apply to Arctic shipping in the future, for instance regarding the use of heavy fuel oil, already prohibited in the Antarctic. Conforming to these regulations reduces the net economic gains of shorter transit times. While the Northern Sea Route could still be an economically viable option under specific circumstances – mostly for bulk shipping from the Russian Arctic – the market potential for other types of shipments remains highly uncertain (Kiiski, 2017[61]; USCG, 2017[60]). Should the Arctic become reliably ice-free at some future date, however, this could increase the likelihood of more Arctic shipping.

What are the implications of trade route changes for international freight transport?

The expansion of rail cargo transport between China and Europe has gathered momentum. Rail freight flows between East Asia and the EU are expected to increase at an annual growth rate of 14% (UIC, 2017[56]). Modernising infrastructure and improving the efficiency of customs processes at border crossings could shorten transit times by four to seven days on Euro-Asian Transport Linkage Routes. In Africa, the impacts of increased infrastructure investment are beginning to materialise. The construction of the Mombasa-Kampala corridor between Kenya and Uganda, for example, reduced transit times from fifteen to five days (OECD, 2011[18]). In Namibia and Zambia, the Walvis Bay Corridor Group has reduced the Southern African Development Community clearance time from forty-eight to two hours.

Using the Northern Sea Route for maritime freight between Northern Europe and Japan could reduce voyage distances by 37% relative to routing through the Suez Canal (Buixadé Farré et al., 2014[62]). Distance from Northern European ports to Korea would be reduced by 31%, to China by 23% and to Chinese Taipei by 17% (Bekkers, Francois and Rojas-Romagosa, 2018[63]). Regular use of the North-West Passage could reduce voyage distance between North America and large ports located in Northeast Asia by up to 20% (Ørts Hansen et al., 2016[64]). For trade between South Asian countries and southern European countries, however, the conventional route via the Malacca Straits and the Suez Canal remains shorter. Melia, Haines and Hawkins (2016[65]) model future reductions in sea ice and find that future transit between Europe and Asia will be reduced by ten days by 2050, and by 13 days in subsequent years. Routes between Asia and North America only stand to save four days because the route through the Panama Canal is relatively short.

Box 5.4. Enhancing freight connectivity in Central Asia

Freight connectivity is fundamental to increasing the competitiveness of countries and promotes economic growth, social integration and development. Improved freight connectivity can benefit countries and regions by providing peripheral areas better access to domestic and international markets for trade, reducing costs for the domestic economy through improved infrastructure and services, relieving congestion and augmenting revenues from expanded transit.

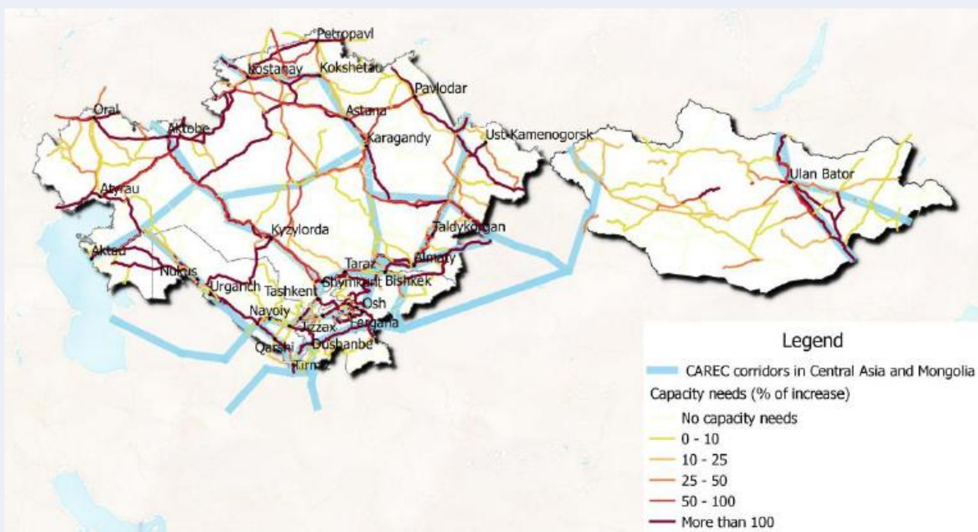
Central Asia is characterised by relatively poor connectivity, despite its historical role as a land bridge between Asia and Europe. The freight volumes passing through the region between Asia and Europe are currently less than 2% of what is carried by sea. The region lags behind others on several dimensions of connectivity and integration, which hinders the development of trade. Economic integration in the area is limited by a low density of settlement and economic activity, infrastructure bottlenecks, ageing road and rail networks, long distances to major markets and to sea ports, as well as numerous regulatory and policy barriers to cross-border flows.

In the context of an OECD project funded by Kazakhstan, the International Transport Forum (ITF) reviewed freight connectivity in Central Asia with a focus on Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan and Uzbekistan. The assessment included a) an analysis of the current level of connectivity in the region with regard to the needs of the regions' economies and the efficiency of freight and logistics networks; b) a review of countries' transport and logistics strategies including infrastructure investments plans; and c) identification of possible future bottlenecks and missing links under alternative trade and policy scenarios.

The results showed that current investment plans in the region will improve connectivity but are likely insufficient to accommodate future trade growth. To prepare for future growth and to improve connectivity, the Central Asian countries have developed national infrastructure plans and are participating in programmes such as the Central Asia Regional Economic Cooperation (CAREC), the Transport Corridor Europe-Caucasus-Asia (TRACECA) and China's Belt and Road initiative which aim to develop international economic and transport corridors.

Quantitative analysis based on the ITF international freight model showed, however, that even with implementation of the planned infrastructure projects capacity on many links will be insufficient to accommodate all future freight flows. As Figure 5.11 shows, demand for infrastructure capacity increases by 2030 on both international corridors as well as regional connections. Existing infrastructure plans focus on key international corridors, yet ensuring local business are connected to the main corridors is crucial for realising the benefits from agglomeration economies.

Figure 5.11. Projected capacity needs for road and rail freight transport, 2030



Reducing the strain on capacity requires infrastructure improvements, such as the construction of new lanes and refurbishment of existing ones, as well as efficiency improvements (e.g. use of high capacity vehicles, development of consolidation centres, or electrification of rail lines).

Other measures can also improve regional connectivity, such as improving border crossing facilitation to reduce waiting times. Refining the national and regional logistics strategies as well as enhancing institutional capacity for making evidence-based decisions and planning under uncertainty. Strengthened regional and international cooperation will also contribute to shorten travel times and make them more predictable, lowering the costs for moving goods along international corridors. Further insights can be found in ITF (Forthcoming[66])

Although they shorten transit distances, new maritime routes through the Arctic may not reduce the climate-related impacts of shipping activities in a significant way. This is mostly due to the difficult sailing conditions in the Arctic and the implications this has for fuel efficiency. In open waters, ships are not required to change their speed very often and can optimise the engine load and fuel efficiency. In the Arctic, this is not the case. Often adverse weather and shallow seas require frequent changes in speed in direction, often making engine optimisation impossible. Highly variable engine loads reduce fuel efficiency and generate up to 50% more black carbon (Lack and Corbett, 2012[67]), the negative effects of which are exacerbated when emitted in the Arctic (Yumashev et al., 2017[68]).

More maritime freight via the Arctic could increase trade volumes and shift emission-intensive production in Northeast Asia. As a result, the potential gains permitted by shorter transit distances in the Arctic may be more than offset by the negative emissions impacts associated with this activity (Bekkers, Francois and Rojas-Romagosa, 2018[63]; Lindstad, Bright and Strømman, 2016[69]).

Rail freight rates between China and Europe have dropped from thirteen to five times the rates of maritime transport (Merk, 2016[70]). This gap between rail and sea freight rate could continue to narrow if the cost increases of the 2020 sulphur emissions cap can be reflected in maritime transit prices and ocean freight rates pick up. Substantial subsidies from Chinese regional governments to Eurasian rail services, on the order of USD 2 000-2 500 per TEU, could at some point be phased out, which would also diminish the financial viability of rail freight in the region (Rail Freight, 2017[71]).

Cooperation with Russia will be crucial in ensuring continued freight flows through the region, since the current Trans-Siberian and Baikal-Amur rail links on the Russian rail network are suffering from capacity shortages, which has limited the growth of rail transit volume through Russia (Global Risk Insight, 2017[72]). The implementation of more stringent regulations on emissions and pollutants from maritime freight could also result in a shift towards rail freight. Regular operation of container block trains constitutes the most competitive, logistics market-oriented model for enhanced operationalisation Euro-Asian Transport Links (EATL) inland routes. Even if freight volumes on the inland routes will never approach those on maritime links, they can be increasingly used for high-value and time-sensitive freight. In Africa, trans-continental freight transport options could lead to increased intra-African trade and could also shorten international trade routes by 2050, if current and planned transit infrastructure projects in Africa continue to reap similar benefits in terms of cost and time savings.

With respect to the potential for increased maritime freight transit in the Arctic, it is estimated that by 2050 the entire Arctic coastline and most of the Arctic Ocean will experience an additional 60 days of open water each year on average, including a range of areas that will experience more than 100 days additional days of open water (Barnhart et al., 2016[73]). Favourable meteorological conditions and infrastructure and technical solutions could conceivably even allow year-round operations by 2030 (Bekkers, Francois and Rojas-Romagosa, 2018[63]), though uncertainty around the first ice-free year in the Arctic is estimated to be about 20 years (Jahn et al., 2016[74]; Notz and Stroeve, 2016[75]).

As a result, the Russian Federal Agency for Maritime and River Transport expects a six-fold increase in the volume of maritime freight in the Arctic over the next three years. China has included the Northern Sea Route in the scope of its Belt and Road Initiative since June 2017 and released a white paper outlining its plans for a "Polar Silk Road" in the Arctic in 2018 (The State Council Information Office of the People's Republic of China, 2018[76]). Despite indications of steady growth of sea traffic on the Northern Sea Route, however, a significant amount of uncertainty remains with regard to future sailing conditions in the Arctic and the cost-effectiveness of this transit. Given this uncertainty and the likelihood of negative climate impacts of black carbon emissions, the potential for new maritime routes in the Arctic to contribute to significant decreases in CO_2 emissions appears limited at this time. Furthermore, increasing cargo transport by rail could displace some of the anticipated rise in maritime traffic in the Arctic region.

Despite the ostensible advantages with respect to distance and transit time, substantial economic risks of maritime travel through the Arctic remain, including reductions in fuel efficiency, uncertainty with respect to arrival dates, and safety-related risks for their crew and vessels. These factors can erode any economic savings from transit via Arctic routes and will prevent their more rapid adoption. Some evidence suggests that the Northern Sea Route will be profitable for ordinary merchant ships only by 2040 (Ørts Hansen et al., 2016[64]). Nonetheless, registered traffic had a five-fold increase on the Northern Sea Route in the past decade, and depending on the evolution of climate conditions and infrastructure investments this can become a viable option in the future.

New trade routes will not affect emissions significantly, but can change the face of transport networks

New trade routes will have no significant impact on CO_2 emissions from freight or global freight volumes, according to the simulation results for this *Transport Outlook*. A shift in trade routes would reduce transport volumes by 2% (3% for seaborne freight) and emissions by 1% in 2050, compared to the current ambition scenario.

There would nonetheless be very important impacts on global logistic chains and transport networks. The Mediterranean Sea and the Indian Ocean would see a drop in freight traffic of one fifth (21% and 19% respectively) by 2050 compared to current ambition scenario, whereas traffic in the Artic that is currently marginal would increase exponentially surpassing volumes in the South Pacific or Caribbean. Ports along the Suez route between East Asia and Northern Europe would lose traffic compared to the current ambition scenario. Those located in strategic positions along the new Artic route would see significant increases in this simulation, with Busan in Korea registering the largest increase, above 50% compared to the current ambition scenario. Figure 5.12 depicts the projected percentage change in tonnes of freight transport flows and loaded/unloaded cargo in 2050 in a new trade routes scenario compared to the current ambition scenario.

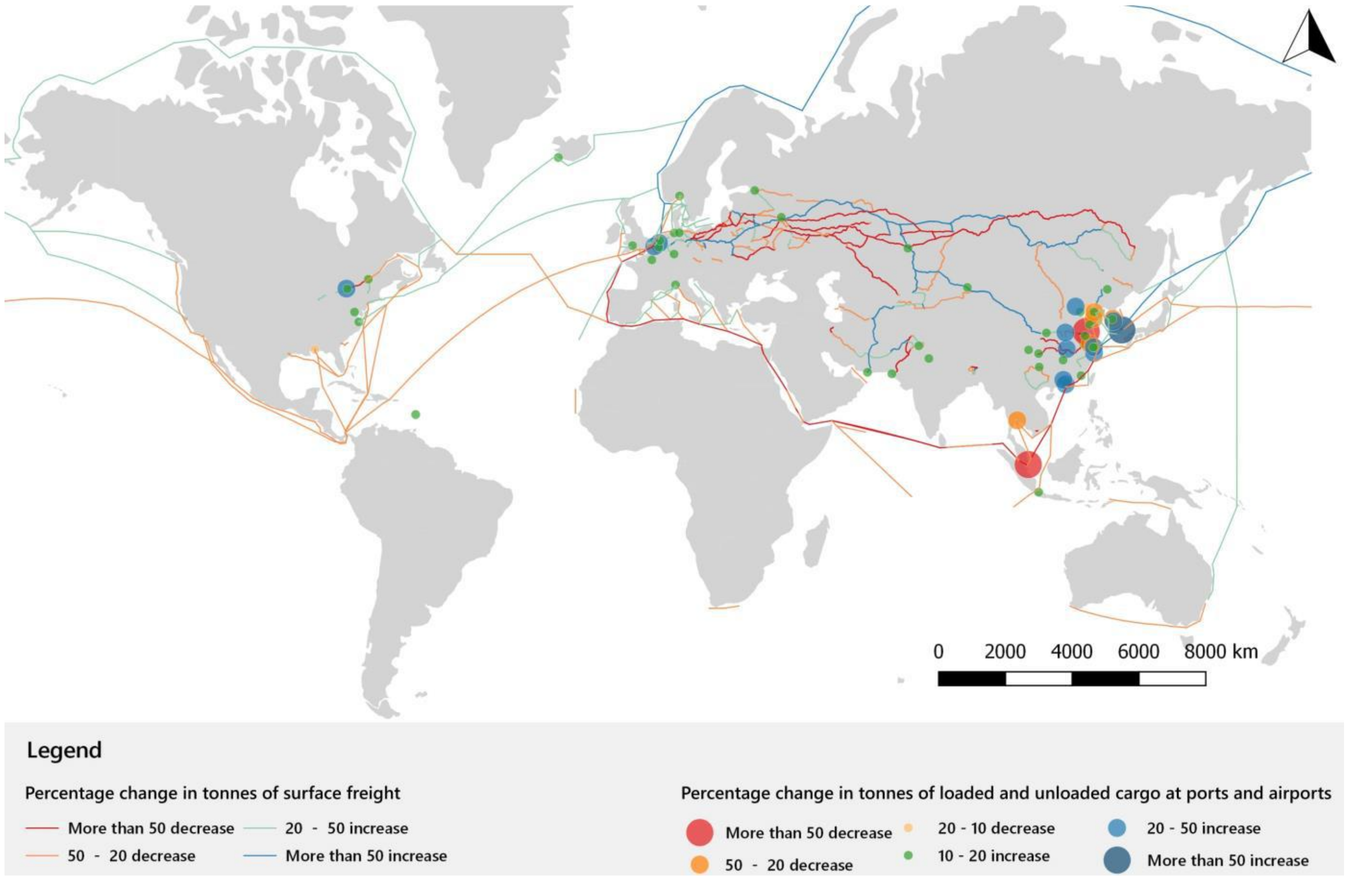
The projected shift in transport flows would also impact the surface transport networks that provide access to the ports. In China and Europe especially, inland flows adjust to changing patterns in maritime routes. This can lead to extra capacity along routes that lose traffic and to congestion in segments where traffic will grow.

In Eurasia, connectivity improvements associated with existing initiatives and other projects leads to an increase in rail volumes compared to the current ambition scenario – although not at the scale of regular shipping in the Artic. The results also show a consolidation of flows on the rail lines that will be improved. In Central Asia, better access to oceanic ports can also produce visible changes in the routes used to access the sea from this region.

Simulation of aggressive disruption of trade routes (employing the specifications shown in Table 5.7) shows the impact of significant infrastructure improvements – namely rail, but also road - along Eurasia and opening up the Artic to commercial shipping without impediments from Europe to East Asia and East Coast of America to East Asia (the latter still with higher costs than average). How likely this will actually be is a matter discussed above and not yet clear.

Figure 5.12. Shift in transport flows in the new trade routes scenario by 2050

Percentage change in tonnes compared to current ambition scenario



Energy transition for long-distance road freight

Road freight's contribution towards freight CO_2 emissions is sizeable and its relevance for efforts to decarbonise the transport sector as a whole is increasing. A number of decarbonisation strategies have been identified, including improving fuel efficiency and mainstreaming the use of alternative energy sources. Important near-term mitigation measures comprise efficiency improvements such as aerodynamic retrofits, reduced tire rolling resistance, vehicle weight reduction, enhanced engine efficiency and hybridisation. Ultimately, decarbonising road freight will hinge on a transition to ultra-low and zero-emission technologies.

This transition will be particularly challenging given the weight of heavy duty vehicles (HDVs) and the long distances they need to cover. Electric road systems (ERS) and hydrogen fuel cells currently represent the most feasible technologies for mitigating road freight emissions while meeting the energy demands of the sector. However, progress in battery technology such as super-fast chargers and battery swapping systems, could radically change the trajectory of the energy transition in road freight. Breakthroughs in low-carbon liquid fuels should also not be ruled out. Even if not foreseeable at present, advanced biofuels or synthetic renewable fuels ("e-fuels") could come to play a role, as well as an accelerated deployment of carbon capture and sequestration (CCS).

Electric roads systems enable moving vehicles to receive electricity via overhead catenary, ground conductive or inductive technologies. Conductive overhead catenary systems transmit energy via a pantograph mounted on a vehicle's roof, similar to electric trains, trams and trolleybuses. The underlying technology has been in use for more than 130 years and can be integrated and operated within the existing road infrastructure. Conductive rail systems transmit energy to rails in the ground and then to the vehicle via a slide-in current collector system.

Finally, inductive charging systems transmit energy from the road to the moving vehicle wirelessly via a magnetic field, requiring the installation of coils that generate an electromagnetic field in the road as well as receiving coils for electricity generation in the vehicle. This requires no mechanical contact for transmitting electricity. Vehicles that operate on ERS must also be equipped with autonomous energy sources such as batteries or hydrogen fuel cells that power the engine when driving on non-ERS roads. In the case of ERS-compatible battery electric vehicles (BEVs), batteries can be recharged while traveling on an electric road system. ERS represent a promising method for powering long-haul heavy goods transport, but will not be practical for heavy duty vehicles servicing smaller and less frequently used collector roads.

Hydrogen fuel cell and battery technologies could be used as a complement to electric roads in the regions or trip legs that are not covered by ERS infrastructure. The most common method of producing hydrogen is through a steam reforming process that uses fossil fuels such as natural gas. Hydrogen can also be produced from the electrolysis of water using electricity, although with low efficiency levels. Hydrogen is stored in fuel cells and converted to electricity to power movement.

What drives the transition to renewable energy in long distance road freight?

An important factor in the development of electric road systems and hydrogen technologies for powering road freight transport are the costs associated with their uptake. To make them an attractive option and facilitate uptake at scale, the infrastructure costs of alternative fuels could not be borne solely by fleet owners in order for it to be attractive enough to adopt.

Several estimates suggest that electric road systems are characterised by lower total costs than other alternative fuels (Cambridge Econometrics, 2018[77]; Connolly, 2017[78]; Kasten et al., 2016[79]; Siemens, 2017[80]). The cost of ERS will depend on the technology used (catenary overhead, conductive rail or inductive charging) and the autonomous drivetrain type of the heavy duty vehicles (i.e. whether the vehicles can remain in electric-drive mode on roads not equipped with ERS), for how long, and whether the vehicle battery can be recharged at charging points. Table 5.6 provides an overview of cost estimates for the different ERS technologies. Cost estimates for electrifying vehicle drivetrains depend on the reference vehicle, the type of electrification that is envisaged (hybrid or full battery electric vehicle), the battery system that defines the electric drive range of the vehicle (i.e. the distance the vehicle can run on battery power when being outside of an ERS), and the costs for allowing the vehicle to be dynamically charged via an ERS. Battery costs and the cost of hybridisation and electrification are expected to decrease significantly in the future as battery technology advances and economies of scale manifest themselves.

Table 5.6. Cost estimates for electric road systems

Type of system	**Infrastructure costs**(1) (million EUR/km)	**Vehicle costs**(2) (EUR)	**Infrastructure maintenance costs** (% of investment costs)
Overhead catenary	2.2	+50 000 (in 2020) +19 000 (in 2050)	2.5
	1.5	+50%	—
	1.5-2.5	+40 000 (in 2020) +25 000 (in 2030) +15 000 (in 2040)	4.0
	1.6(3) (0.8 in long run)		
	0.7-2.0	+5 000 (compared to a hybrid heavy duty vehicle)	—
Conductive rail	0.4(4)	—	—
Inductive charging	>3.1	—	—

Note: (1) Per kilometre of two-lane highway, fitted on existing road infrastructure. Includes costs for electrical wiring, rails and poles, connections to the electric grid, substations with transformers, control units, related civil works etc. (2) Compared to a conventional heavy duty vehicle unless stated otherwise. Includes costs to hybridise or fully electrify the drivetrain of the vehicle. (3) Provided in USD for one lane. (4) Assuming that 20 000km of roads in Sweden are electrified.
Source: Kasten et al. (2016[79]); Jancovici, Schuller and Borie (2017[81]); CCGD (2017[82]); IEA (2017[9]); Viktoria Swedish ICT (2013[83]); eRoadArlanda (2018[84]).

Under current economic and technological conditions, overhead catenary systems are probably the most cost-effective system (Jancovici, Schuller and Borie, 2017[81]; Kasten et al., 2016[79]). Although the total infrastructure costs for batteries, hydrogen and electric road systems would be similar, ERS is likely to be least costly over time for an equivalent number of zero-emission vehicles in service (Kasten et al., 2016[79]). Operational costs will also depend on the share of the vehicle mileage on ERS-equipped roads, the price difference between the conventional fuels (i.e. diesel) and electricity, and the subsidies, preferential policies or tolls that may be applied in certain regions.

None of these systems are currently in widespread use. Much of the discussion regarding the cost-benefit comparison of alternatives is based on assumptions of future developments that are highly uncertain. A survey carried out by the ITF found that road freight experts see the lack of existing infrastructure, difficulty in scaling up production, and high vehicle costs as the greatest barriers to the adoption of electric road systems (ITF, 2018[6]).

As ERS are not a practical solution for all parts of the road network, hydrogen fuel cell technology could play a role in mitigating emissions from non-ERS road freight travel. Hydrogen is a relatively energy-dense fuel compared to current battery technologies. This gives hydrogen fuel cell electric vehicles (FCEVs) greater autonomy than plug-in electric vehicles (PEVs), as well as more cargo space. Although the tank-to-wheel (TTW) efficiency of hydrogen fuel cell technology is high, the production of this fuel is relatively inefficient compared to electricity generation. Low overall energy efficiency, high costs for vehicle, network and infrastructure, as well as the challenge of scaling up production are among the barriers to greater uptake of FCEVs (ITF, 2018[6]).

Considerable uncertainty surrounds the magnitude of the cost reductions associated with fuel cell systems in the future, particularly with respect to the coextensive developments in battery technologies. Financial tools may either encourage the uptake of these technologies (e.g. purchase subsidies) but may also be used to recover the costs associated with infrastructure construction and maintenance.

Box 5.5. Low-carbon fuels

Liquid fuels remain prevalent in transport thanks to their relatively high energy density, portability, storage stability, and ease of delivery. This is the case in particular for high-mileage heavy duty vehicles for cargo transport. The extensive distribution infrastructures in place give liquid fuels an additional advantage. Alternative energy sources for road freight transport such as electricity or fuel cell require more investment to deploy and a longer time scale to achieve a meaningful market share.

Among the technologies capable of reducing the carbon footprint of road freight and delivering climate-friendly mobility in terms of lifecycle emissions are low-carbon intensity crude oil, upstream and refinery carbon capture and storage/utilisation, advanced biofuels and drop-in low-carbon fuels derived from water and CO_2.

Even if alternative energy sources for mobility such as electricity are making rapid advances, the vast majority of global mobility demand will continue to rely on burning fossil fuels for decades. Crude oil production, transport, and refining into finished products account for as much as 15-40% of fuel well-to-wheel greenhouse gas emissions.

While in use around the world for quite some time, biofuels still make up a small portion of total fuel consumption in most regions. Only in very few countries do they have a significant share of the fuel use, among them in Brazil and the United States. Most biofuels are crop-based (e.g. sugar cane, corn or vegetable oil), which raises concerns regarding indirect land use change.

A dramatic increase in the use of crop-based biofuels would mean a substitution of food crops and large-scale conversion of arable land - unless mitigated by yield-intensive crop practices and land use policies (Macedo et al., 2012[85]; Nepstad et al., 2014[86]). The carbon emissions originating in these land use changes can offset any emission savings potential from biofuels (Valin et al., 2015[87]).

Where biofuels can be produced from waste, algae or cellulose they become a much more attractive option for decarbonising transport, although such non-crop solutions have proven difficult to scale up. Both crop and non-crop biofuels that involve a fermentation process can offer even lower lifecycle GHG reductions if coupled with CCS.

The caveats do not disqualify biofuels from the set of available CO_2 mitigation solutions for road transport. The impacts of indirect land use change can vary greatly from country to country, for instance. The case of Brazil demonstrates how the widespread adoption of Ethanol produced from sugar cane can contribute to lower emissions even when the total life cycle and land use changes are taken into account (La Rovere, Pereira and Simões, 2011[88]; Rothkopf, 2008[89]; Schroeder, 2010[90]). This being said, conditions in Brazil (a climate suitable for sugar cane, large amounts of arable land and a well-developed agro-industrial complex) cannot be easily reproduced at global level.

This highlights an important insight: the pathways to decarbonising transport should be adapted to the specific conditions of different regions, as solutions that may have a high emissions reduction potential and convincing economic case and in one place might not be applicable to others.

The growing awareness of the problems associated with land-use change has spawned more and more interest in the scientific community for alternative biofuels. Among these are synthetic fuels made from water and CO_2 as primary inputs. The principle of synthesising fuel is hydrogen generation via electrolysis or direct water splitting, and reacting it with CO_2 into molecules which are blended with the fossil base fuel, to reduce overall carbon intensity. If the electricity required for the synthesis is from renewable sources and the carbon atoms obtained through reducing CO_2 (e.g. from captured combustion or captured from the air), the synthetic fuel is nearly carbon neutral. Gradually over time, the proportion of synthetic fuel blended into the fossil base could increase and increase the mitigation effect. A co-benefit of synthetic fuels is combustion is substantially cleaner than fossil fuels in terms of nitrogen oxides (NOx) and soot emissions.

What are the impacts of transitioning to alternative fuels in long-distance road freight?

Battery electric vehicles and vehicles on electric roads do not generate tailpipe emissions. The same is true for and fuel cell electric vehicles (FCEV), yet lifecycle greenhouse gas emissions from FCEVs have been estimated at twice those of diesel trucks, at least with the current electricity mix in Germany (Kühnel, Hacker and Wolf, 2018[91]). The well-to-wheel energy efficiency of heavy duty vehicles on electric road systems have been estimated at 77%, compared to 62% for battery electric trucks and 29% for hydrogen trucks (Kasten et al., 2016[79]; Moultak, Lutsey and Hall, 2017[92]). Among ERS technologies, overhead catenary systems are considered to have the greatest energy efficiency. Furthermore, Overall emissions reductions of ERS will depend on the degree of electrification of heavy duty vehicles, the system's overall energy efficiency and the share of travel on non-ERS equipped roads.

In terms of the impact of ERS on the electricity grid, ERS is expected to be less demanding than more conventional battery vehicles. This is because the continuous electricity supply via the ERS allows for smoother load profiles on the electricity network. The energy storage capacity made possible by hydrogen fuel can help to foster and maximize the use of electricity produced from renewable sources.

Decoupling road freight transport from CO_2 emissions will require significant investments. Substantial financial commitments will be required from private companies, for instance the vehicle manufactures that will have to adapt their production. Significant funding will also be required from the public sector, notably for the creation of distribution and fuelling/charging networks. All three types of electric road systems are currently being tested, mainly in Germany, Sweden, France, China, Japan and Korea (eRoadArlanda, 2018[84]; Heise, 2017[93]; Jacob and Caso Florez, 2018[94]; Scania, 2016[95]; Transport & Mobility Leuven, 2017[12]). These tests will be useful to identify viable business models, regulatory requirements and international standards. They will also help to address safety concerns. New players from outside transport might become important partners, for instance utility companies. These could help shape the business models for electric road systems or charging station networks.

In many countries, the great majority kilometres driven by heavy duty vehicles are concentrated on relatively small portion of the road network (Kasten et al., 2016[79]). Thus, new infrastructure for alternative energy sources will most likely be implemented on trunk routes with a high volumes of freight traffic, for instance between distribution centres, ports or rail terminals. Here, electric road systems may be financially viable for private operators within as little as five years (Schulte and Ny, 2018[96]). Here, they will also generate the greatest CO_2 reductions. A network effect could emerge after 2030, especially if framework policies such as strict emission standards for heavy duty vehicles put sufficient pressure on vehicle manufacturers and operators. Because road freight trips are often international, a successful deployment of electric road systems will also require concerted international efforts to ensure inter-operability across borders.

With respect to hydrogen, some public money is already being invested in hydrogen re-fuelling stations. These are now accessible in a number of cities worldwide. Projections of the future uptake of fuel-cell electric vehicles are limited, despite the substantial cost reduction potential of hydrogen technologies (US DOE, 2017[97]). The reason are the investment risks of infrastructure development (IEA, 2017[98]). If battery technology for heavy trucks on long-haul operations advances significantly, battery-electric vehicles could supplant electric road systems and fuel cell electric vehicles as the most promising CO_2 mitigation technology for road freight.

In sum, the large-scale deployment of electric road systems and hydrogen over the next decade appears unlikely. In the absence of a significant scaling-up of current efforts, ERS and hydrogen fuel cell technologies are only likely to become mainstream in the mid- to long-term, perhaps between 2030 and 2050. The deployment of ERS and heavy duty vehicles powered by hydrogen fuel cells will vary across countries and regions, depending on the (cost) attractiveness of alternatives to mitigate CO_2 emissions, the state of the electric grid, the road system, and the political will to achieve climate goals.

It is also highly unlikely that a single technology will be able to replace diesel or gasoline internal combustion engines. There is a degree of complementarity between different solutions: vehicles powered by a direct supply of electricity through catenaries can also have batteries, fuel cells or combustion engines running on biofuels. Options that require large-scale infrastructure investments might not be available in some regions, or be less cost-effective there. Achieving total, or near-total, decarbonisation will require a range of solutions that are complementary and can be adapted to different contexts.

Energy transition for long-distance road freight is necessary to decarbonise road freight

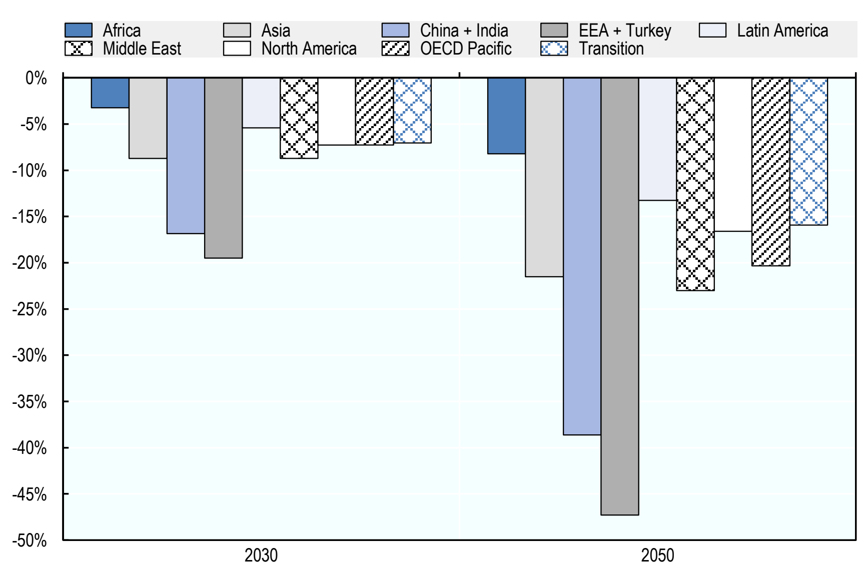
Non-urban road freight currently accounts for 87% of road transport volume and 77% of its emissions. It contributes 43% of freight transport emissions, more than any other mode. Its share of total transport CO_2 emissions, including those of passenger transport is 16% of emissions.

Thus, efforts to decarbonise transport will fail without a successful energy transition for long-haul road freight. Of the disruptions evaluated for this *Transport Outlook*, replacing fossil fuel as the main energy source for long-haul road freight achieves the second-highest impact on freight emissions, with a 16% decrease in CO_2 emissions by 2050 compared to the current ambition scenario.

The impact of an energy transition in long-distance will vary across world regions. The differences are explained by varying adoption rates assumed and the shares of road in surface transport in each region. Europe will thus see bigger decreases in emissions from this transition, because it has a high adoption rate and high modal share for road. North America will see smaller gains because the share of road is smaller and hence changing its energy source has less impact on emissions.

Figure 5.13. Projected CO_2 emissions from surface modes in the energy transition scenario by region, 2030-50

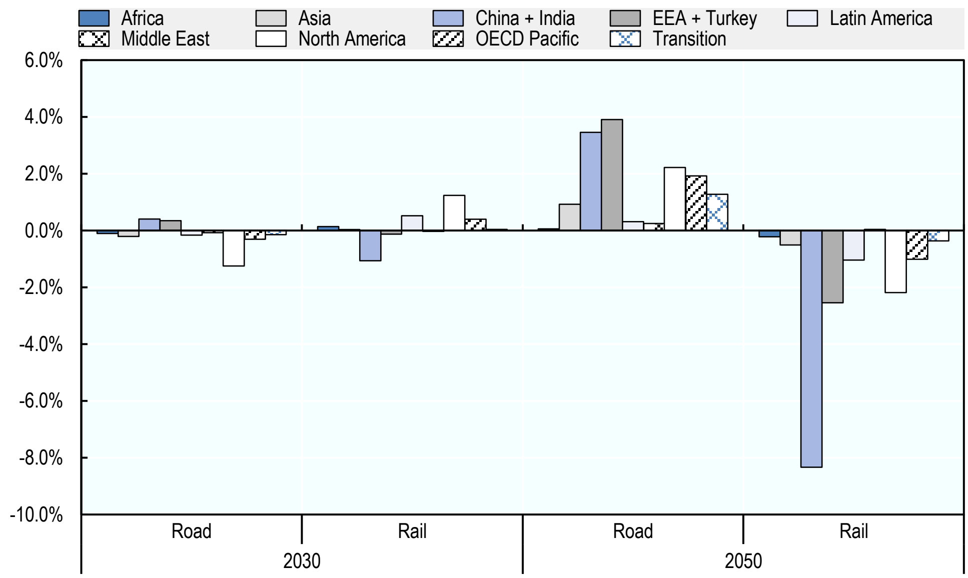
Percentage change in tonnes compared to current ambition scenario



StatLink http://dx.doi.org/10.1787/888933972924

Figure 5.14. Projected road and rail freight transport volumes in the energy transition scenario, 2030-50

Percentage change in tonne-kilometres compared to current ambition scenario



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An energy transition also influences transport costs. These will be higher initially but then gradually fall below those of current internal combustion engines, due to lower fuel and maintenance costs as well as the abatement of infrastructure costs. Again, there will be variations by region.

A shift towards low- or zero-carbon fuels also impacts demand and modal share. Because costs are already lower there, road will gain modal share from rail in Europe by 2030, but not in other regions. By 2050, with wider deployment and falling costs across the world, a more general shift from rail to road takes place, particularly in China and India. This assumes, however, that there will not be equivalent cost decreases or other counter-acting initiatives from the rail sector.

Autonomous Trucks

Road freight is particularly suited to full automation. Self-driving trucks would enable significant savings on labour costs, which currently comprise a third or more of the operating costs in Europe and North America. There is thus a strong commercial incentive to introduce automated trucking.

Most of the long-haul heavy duty operations in developed countries take place on highways where automation is easier to implement than in highly complex urban traffic settings. Not least, driverless trucks will be able to operate 24 hours per day, thus optimising asset use, making it easier to avoid peak hours and providing greater flexibility in fleet management.

Important barriers to driverless trucks exist nonetheless. Specifically, more progress is needed in vehicle-to-everything (V2X) communication and in standardisation.

Most experts agree that driverless trucks will become a reality in ten to twenty years, albeit only on specific highway corridors between logistic centres with large volumes of demand. Road freight is ahead of other sectors in this field, but other markets also show great potential like public transport where several trials have taken place and services are already operating in cities (ITF, 2018[99]).

Besides individual self-driving trucks, convoys of semi-automated vehicle convoys linked via vehicle-to-vehicle communication systems ("platoons") are in advanced tests.

What drives the uptake of autonomous trucks?

The significant cost reductions and increases in operational efficiency provide strong incentives for the industry to develop and deploy autonomous trucking. The way and speed with which automation will be adopted depends on a host of factors. Some technological advances are still needed. The current infrastructure will need to be adapted. Clarity is needed on the exact business model. Questions regarding insurance and liability require answers. Public concerns about safety and security risks must be answered – and those answers might drive up costs and limit the commercial attractiveness of driverless trucks.

Wide spread adoption of automated road freight vehicles and operations needs common standards across the business, or at least on sufficiently large markets. The regulatory framework thus plays a critical role, as it conditions to which extent the industry will be able to enjoy the benefits of automated road freight. Presently, a degree of uncertainty persists on how permissive or restrictive the regulatory regimes will ultimately be, these developments are associated with the safety, security and congestion impacts of this technology (something further discussed in Chapter 3). Nonetheless, as noted above, automation applied to trucks moving along highways not passing through highly congested urban areas at this stage seems to have fewer obstacles and clearer benefits than for individual passenger-vehicles.

Also presently uncertain is the level of automation that can be attained in road freight. It is not clear that fully driverless trucks (i.e. level 5 automation according to the standard classification of SAE International, see Chapter 3) will be possible for all road freight operations. Yet it is certain that vehicles will be equipped with systems that will increasingly assist drivers. Such lower levels of automation can already increase fuel efficiency, improve routing and change the current role of truck drivers. All of which can still contribute to reduce operational costs.

What are the implications of autonomous trucks use for transport systems?

Autonomous trucks and truck platooning can bring significant cost savings. In an expert survey carried out by the ITF, a majority of respondents estimates the cost reduction potential of platooning at 10% or more. Half of the respondents saw an even greater cost-savings potential for fully autonomous vehicles, which they put at greater than 25%. At this point, savings would reach the level of labour costs, which make up between 25% and 45% of the cost of road freight operators. While estimated savings are still at the lower end of the cost scale, operators would also reap indirect benefits, notably the ability to use their trucks more flexibly since mandatory rest times for drivers would no longer be required. Not least, self-driving trucks would provide an answer to the shortage of professional drivers faced by the haulage industry (ITF, 2017[100]).

Truck platooning can decrease the wind drag of vehicles driving closely packed in a column and thereby increase fuel efficiency. But its benefits are more associated with the reduction of operational costs. The contribution of autonomous trucks towards decarbonisation is less clear. They might increase driving efficiency, allow for higher loads and avoid congestion by using off-peak periods. But large cost reductions can lead to higher demand, thus more transport activity and, more emissions rather than less.

More than 50% of experts surveyed by ITF on this question believe that truck platooning will be in general use by 2030 and autonomous vehicles by 2050. There have been already several trials with digitally connected truck platoons (Dutch Ministry of Infrastructure and the Environment, CEDR and RDW, 2016[101]) and autonomous vehicles are already in operation in very delimited and controlled environments like ports and mines. Nonetheless, there are still open questions about the extent to which both these systems will eventually be deployed. As of today, there are no commercial operations with fully driverless trucks even on highways, although some trials with a driver on board have taken place (Davies, 2017[102]).

In view of the uncertainties still surrounding the deployment of fully autonomous trucks, this technology was not included it in the modelling of any baseline.

For a disruptive scenario we assume that the fuel efficiency gains of fully automated road freight vehicles are in line with the most optimistic expectations in the surveyed literature, resulting in a 14% reduction of carbon emission per tonne-kilometre. The operational costs of self-driving trucks per tonne-kilometre are 45% lower than current values, due to lower (or zero) labour cost and higher operational efficiency. In this disruptive scenario, all regions see the use of automated trucks grow more quickly on inter-urban trips than in urban environments. Like with the parameter variations on other scenarios the adoption rates follow a logistic curve to the 2050 target year that reaches a target value by 2050.

Autonomous trucks have moderate impacts on emissions

Overall global CO_2 emissions will not change in a relevant order of magnitude as a result of shifting road freight from conventional to autonomous trucks. There is a slight decrease of 1% by 2050 compared to the current ambition scenario. Significantly lower road costs bring down overall transport costs which slightly increase global transport volumes by 1%. They also induce a shift from rail and inland waterways to road. Transport by air and sea are less affected by this change.

Though there is an emissions decrease from surface modes for most regions there are exceptions, like for North America (see Figure 5.15). This region sees a 15% drop in rail volumes, whereas road freight increases by 18% compared to the current ambition scenario. Among the potential disruption of road freight transport examined in this chapter, autonomous trucks cause the most drastic mode shift towards road and away from rail and inland waterways, more so than HCVs or zero to low-emission trucks (see Figure 5.14, Figure 5.16 and Figure 5.19). Even if autonomous vehicles should be more efficient than current trucks, they will still be more carbon intensive than rail. Hence the emissions increase in North America.

Figure 5.15. Projected CO_2 emissions from surface modes by region in the autonomous truck scenario, 2030-50

Percentage change in tonnes compared to current ambition scenario

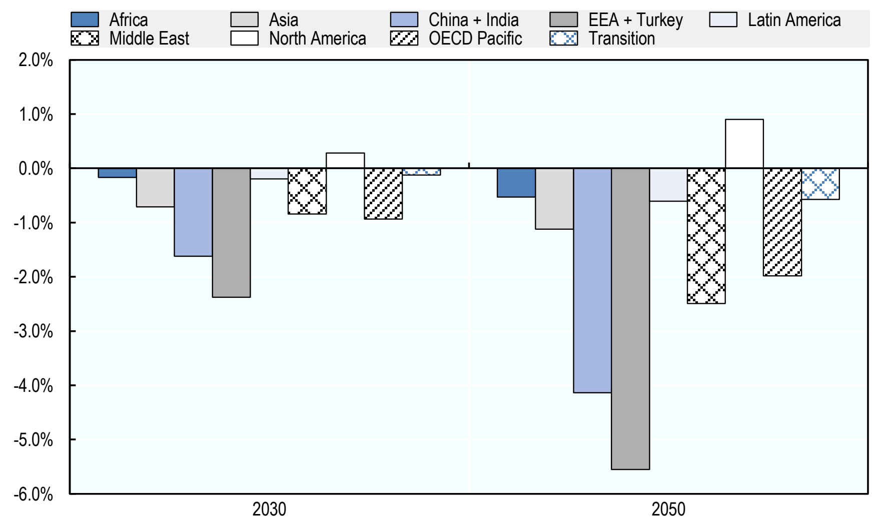

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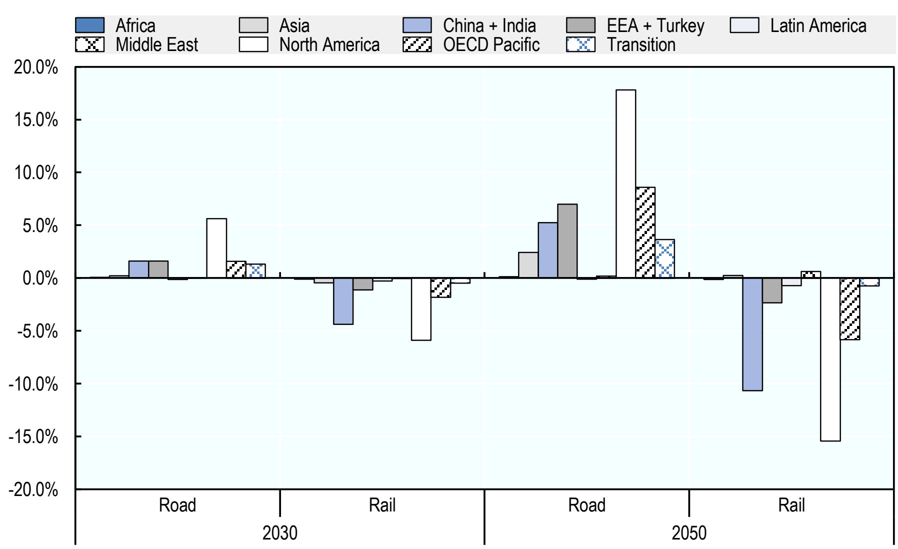
Figure 5.16. Projected road and rail freight transport volumes in the autonomous truck scenario, 2030-50

Percentage change in tonne-kilometres compared to current ambition scenario



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The significant potential of autonomous trucks to cut costs allows higher returns, which can in turn be reinvested in increased efficiency and alternative fuel technologies. Thus, automation can indirectly help to overcome the high initial cost barrier of some of these technologies. On the other hand, a steep decrease in costs that make road transport more competitive can also spur a rise in demand that could offset any efficiency gains. Policy can address this dilemma, for instance by imposing stringent emission standards for automated trucks and ensuring they operate in off-peak periods to avoid congestion.

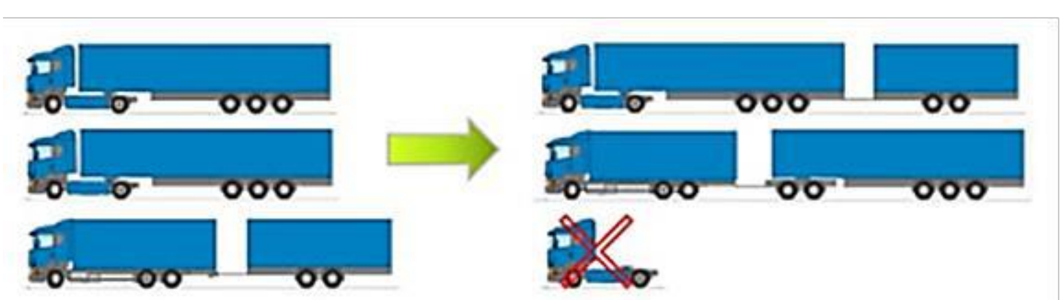
High capacity vehicles

The weight and dimensions of road freight vehicles are nationally regulated. In most countries, heavy goods vehicles are considered to be those weighing more than either 3.5 or 4.5 tonnes. High capacity vehicles (HCVs) are tucks that exceed the general weight and dimension limitations set by national regulations. They usually operate under special provisions within limited geographical areas or on specific routes. HCVs can move more cargo with fewer vehicle-kilometres driven, which results in lower fuel consumption per unit of transported cargo. This has implications for transport operators, cargo shippers, road freight regulators, consumers and the general public.

National standards mean that a 22-metre, 5-axle vehicle weighing 44 tonnes may be considered an HCV in one country but as a standard truck without access restrictions in another. A number of countries have either introduced HCVs permanently or are piloting them in order to explore the impacts that the use of larger and heavier vehicles can entail. Among these countries are Australia, Canada, the United States, Mexico, Argentina, New Zealand, South Africa and several countries in Europe

In the European Union (EU), the European Modular System (EMS) allows member states to choose combinations of existing standardised modules. The EMS therefore allows operators to exceed the general size and weight restrictions by combining smaller modules compliant with the regulation in place. This provision was initially intended to accommodate the larger trucks used in Finland and Sweden since the 1980s. The advantage of EMS is that it allows a high degree of flexibility in adapting vehicles to different situations. Operators have the ability to use longer combinations where possible and shorter combinations or single modules where regulations require it. Figure 5.17 shows how the EMS enables flexible operation of high capacity vehicles.

Figure 5.17. The European Modular System of trucks



Source: Serena (2016[103])

What facilitates the proliferation of high capacity vehicles for road freight?

Operational, market and regulatory drivers are behind the uptake of high capacity vehicles (Aronietis et al., 2016[104]). Operational drivers consist of technology pushes and cost-saving measures. Technology pushes refer to the availability of technology, in this case vehicle modules. The cost-saving measures include the fuel- and labour-related costs that can be reduced per unit of cargo that is transported by high capacity vehicles.

The market drivers of HCV adoption promote cost savings through the competition-induced pressure towards higher performance in road freight operations. Regulatory drivers include applicable government regulations for road freight transport, such as safety- and efficiency-related regulations. Typical policy goals include reducing the number and impact of crashes, improving environmental performance and increasing operational efficiency. The presence of all three types of drivers indicates that the adoption of high capacity vehicles may be quite fast. The main barrier is the lack of a regulatory framework in some regions.

What are the impacts of high capacity vehicles on road freight transport?

Longer and heavier trucks will increase transport costs per truck by 5-12%. Yet 10-50% fewer vehicles are required to transport the same amount of cargo. Thus transport costs per unit of load actually decreases (Vierth et al., 2008[105]). As a secondary effect, such lower haulage costs can in turn shift freight activity away from rail or inland waterways towards road. It may even stimulate additional demand for road freight transport. They can also make it more difficult for less CO_2-intensive but more costly freight modes to win market share. The induced demand effect is unlikely to cancel out the effect of fewer total-vehicle kilometres (OECD, 2011[106]). The effect of HCVs on mode split seems to have been overestimated in prior research (de Jong, 2017[107]).

Indeed, mode shift is only one possible reaction to the reduced costs generated by greater efficiency in road freight transport. Other responses from operators may include changes to the logistics network related to depot locations, shipment size, the consolidation of freight, and reduction of empty driving. They can also include changes to transport demand such as the use of different suppliers, marketing to different customers, or selecting different production locations. In an example from Sweden, increases in road tonne-kilometres originated mainly in other factors than increased efficiency due to the utilisation of HCVs (Vierth, 2017[108]).

The evidence in the literature on the impacts of HCVs has been mixed (Christidis and Leduc, 2009[109]). This in large part due to the varying assumptions on road freight price elasticity and the specific payloads, distances, and costs considered. Empirical assessments of the known impacts are largely positive (OECD, 2011[106]; McKinnon, 2014[110]). In Canada, Sweden and Australia the introduction of HCVs went along with reduced road traffic and CO_2 emissions, for example (Vierth et al., 2008[105]; Woodroffe, 2017[111]). The overall changes caused by introducing HCVs will depend on a number of factors such as the adoption rate, geography of the region, operational patterns of HCV operators, type and density of the cargo, and the networks of competing transport modes.

Capacity increases in truck size beyond 60 tonnes payloads and 25.25 metres length are likely to yield additional environmental benefits. In one study, simulations indicated that further increasing the weight and length restrictions on road freight vehicles in Sweden from 64 tonnes and 25.25 metres to 74 tonnes and 34 metres would decrease CO_2 emissions by up to 12.17 mega-tonnes between 2018 and 2058 (Pålsson et al., 2017[112]). In Finland, the impact of introducing increased weight and height limits of up 76 tonnes and 4.4 metres for road freight vehicles (up from 60 tonnes and 4.2 metres) is estimated to have led to a reduction of 65 000 tonnes of CO_2 emissions in 2015 (Liimatainen and Nykänen, 2016[113]).

The challenge for operators using high capacity vehicles is to optimise vehicle loading. Depending on the cargo type, capacity will be limited either by the specified weight restrictions or by the volume of goods the vehicle is able to carry. Therefore an increase in weight limits will mostly affect dense cargo that tends to limited by its weight, such as steel. An increase in the maximum allowed dimensions of the vehicle will mostly impact the transport of cargo that is limited by volume, such as textiles or footwear.

Emissions produced by diesel-powered road freight vehicles continue to have a detrimental impact on air quality, despite improvements following the introduction of EURO emission and safety classes. Reducing the harmful emissions from diesel fuel combustion is technologically difficult, though. Thus, no further reduction of local emissions from diesel vehicles class is expected in the foreseeable future. Technologies that do not use hydrocarbon fuels, such as electric vehicles, are vastly more promising in the long-term for tackling local pollution and greenhouse gas emissions (see the discussion on e-highways and energy transition above). Although high capacity vehicles primarily offer near-term benefits for reducing CO_2 emissions, they have potential in applications in specific contexts, such as in North America, where US and Canadian vehicles are characterised by radically different environmental performance (Figure 5.18).

Figure 5.18. CO_2 emissions of alternative heavy goods vehicles in North America

Source: Woodroffe (2017[111])

Using 0.037 litres of fuel and emitting 98.79 grammes of CO_2 per cargo-unit, Canadian B-trains are 68% more efficient than US tractor semitrailers, which use 0.063 litres of fuel and emit 165.9 grammes of CO_2 per cargo unit (Woodroffe, 2017[111]). Only the relaxation of existing limits on vehicle size and weight will enable greater uptake of high capacity vehicles limits. Another barrier to the uptake of HCVs is the potential costs associated with updates of existing road infrastructure. These may be needed to accommodate the increased weight and dimensions of high capacity vehicles. To the extent that HCVs reduce traffic volumes, they can conceivably also extend the lifespan of reinforced infrastructure, however (Pålsson et al., 2017[112]).

Stringent enforcement of HCV regulation thanks to the opportunities offered by GPS tracking, automated weighing or vehicle measuring technologies can help to reduce adoption barriers. They can reliably ensure that the allowed weights and dimensions are not exceeded, and that the vehicles stay on specific routes or within designated geographical areas. Since HCVs have specific infrastructure requirements, for instance minimum roundabout radii or maximum load for bridges, it makes sense to limit HCVs to specific parts of the road network and update relevant infrastructure elements on those. Ideally, the areas of operation would be situated where niche transport markets would benefit from efficiency increases to bring higher value to society.

High capacity vehicles have moderate impacts in emissions and modal shift

Simulation results show that the gains in increased average load and logistic efficiency of high capacity vehicles more than make up for the increased volume of activity and overall emissions decrease. This is the case even if the modal shift from rail (and inland waterways) to road is taken into account. Nonetheless, minimising this reverse modal shift and induced demand that results from lower costs of road transport is critical, as without it this alternative might not contribute towards decarbonisation.

Overall, the high capacity vehicles disruption scenario displays a very moderate decrease of 3% in the CO_2 emissions of HCVs compared to the current ambition scenario. Still, this is a more significant decrease than in the autonomous trucks scenarios. The impact on total freight volumes is reduced, although there is a marginal increase in the share of road freight transport compared to rail, but much lower than for the scenario with disruption by autonomous trucks.

Changes in costs were not concentrated in the specific routes where HCVs would operate, but on the wider network of highways and non-urban roads. On the dedicated routes where these types of trucks operate on a large scale the impacts will be magnified, even if the aggregate impacts are moderate.

Figure 5.19. Projected surface freight transport volumes in the high capacity vehicle scenario, 2030-50

Percentage change in tonne-kilometres compared to current ambition scenario

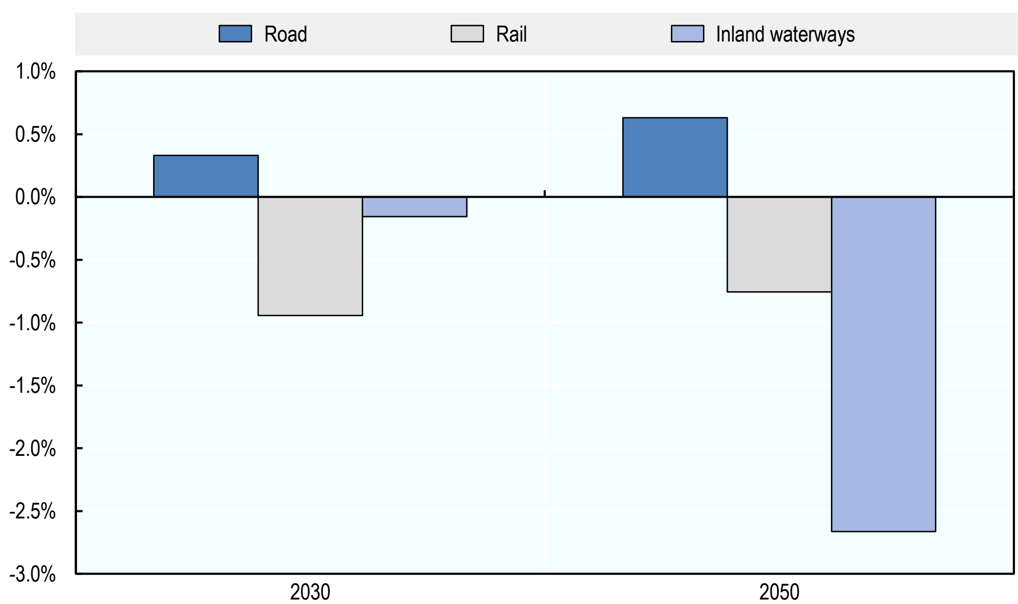


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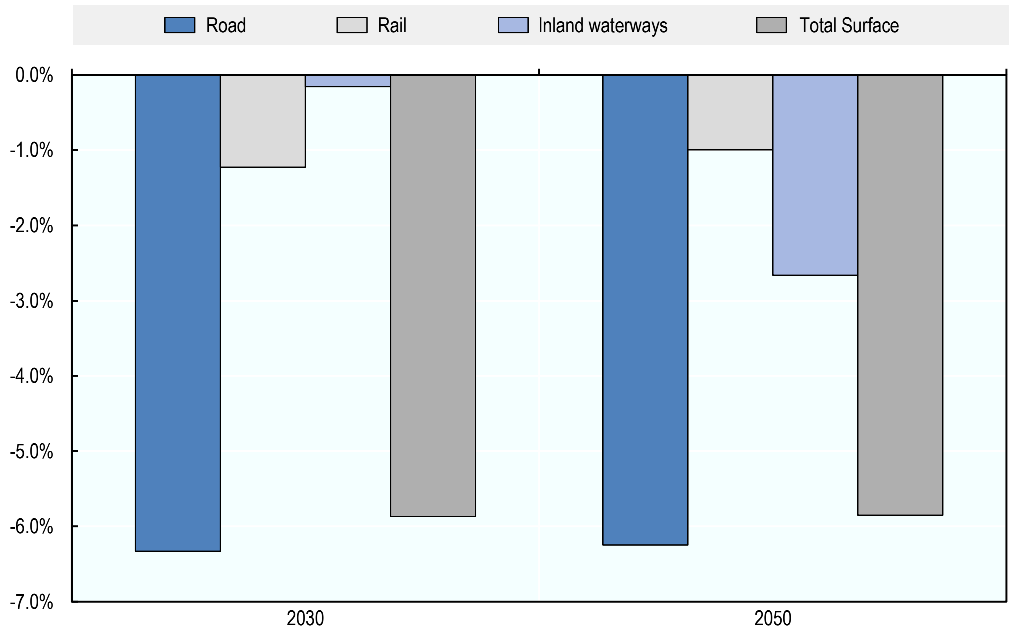
Figure 5.20. Projected CO_2 emissions of surface freight modes in the high capacity vehicle scenario, 2030-50

Percentage change in tonnes compared to current ambition scenario



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Disruptive scenarios in freight transport

Freight-related emissions are estimated to fall 12% below 2015 levels by 2050 in the full disruption scenario, where all the potential disruptions described above are combined and policies are set to target high ambitions in terms of logistical and technical efficiency. Without disruptions and external shocks, policy-induced if needed, it is unlikely that freight emissions can be significantly reduced.

Only applying all logistic and technology levers in combination with the disruptive deployment of energy transition of long distance road freight and the occurrence of exogenous shocks such as a wide scale adoption of 3D printing - that will considerably decrease the growth in trade values - are emission reductions achieved.

Such a scenario is highly disruptive, massively changing transport costs, activity volumes, logistic chains and with new technologies in wide spread use. Although demand still grows in this scenario, its annual compounded growth rate from 2015 to 2050 is 2.5% compared to 3.4% in the current ambition scenario. Transport flows across the networks decrease, although with a few exceptions where new trade routes develop, notably Artic shipping and improved rail lines in Eurasia.

The shifts that take place in this scenario require new infrastructure, for instance, new investments will be needed to allow for an energy transition. At the same time, there may be reduction in freight flows at certain corridors resulting in overcapacity in some links and nodes of the network (e.g. ports and airports). This underlines the relevance of investment planning and project appraisal in the transport sector, incorporating as much as possible risk analysis and uncertainty. It also points to the paramount importance of data both to have a better understanding of current dynamics and the potential impacts of future developments.

International trade by air and sea will see the sharpest decreases in activity compared to our current ambition scenario. Inland waterways would also have significant losses since it is closely associated with maritime shipping. Road and rail would lose the least, particularly road, which although decreasing is still able to capture some traffic from rail and inland waterways.

Table 5.7 describes the assumptions of disruptive and non-disruptive development pathways for each of the potential disruptions discussed above. Table 5.8 specifies how these alternative pathways are combined in three alternative scenarios. In addition to a scenario in which all disruptions occur (full disruption scenario), the logistics scenario assumes that only exogenous and logistical disruptions occur, specifically e-commerce, 3D printing, a decrease in international transports of coal and oil, the opening of new trade routes, and improved logistical efficiency (or average loads) as employed in the high ambition scenario (based on the IEA's EV30@30 scenario). The technology scenario assumes that disruptions of a technological nature occur, specifically autonomous trucks, high capacity vehicles and energy transition for heavy goods vehicles.

Figure 5.21. Shift in transport flows in the full disruption scenario by 2050

Percentage change in tonnes compared to current ambition scenario

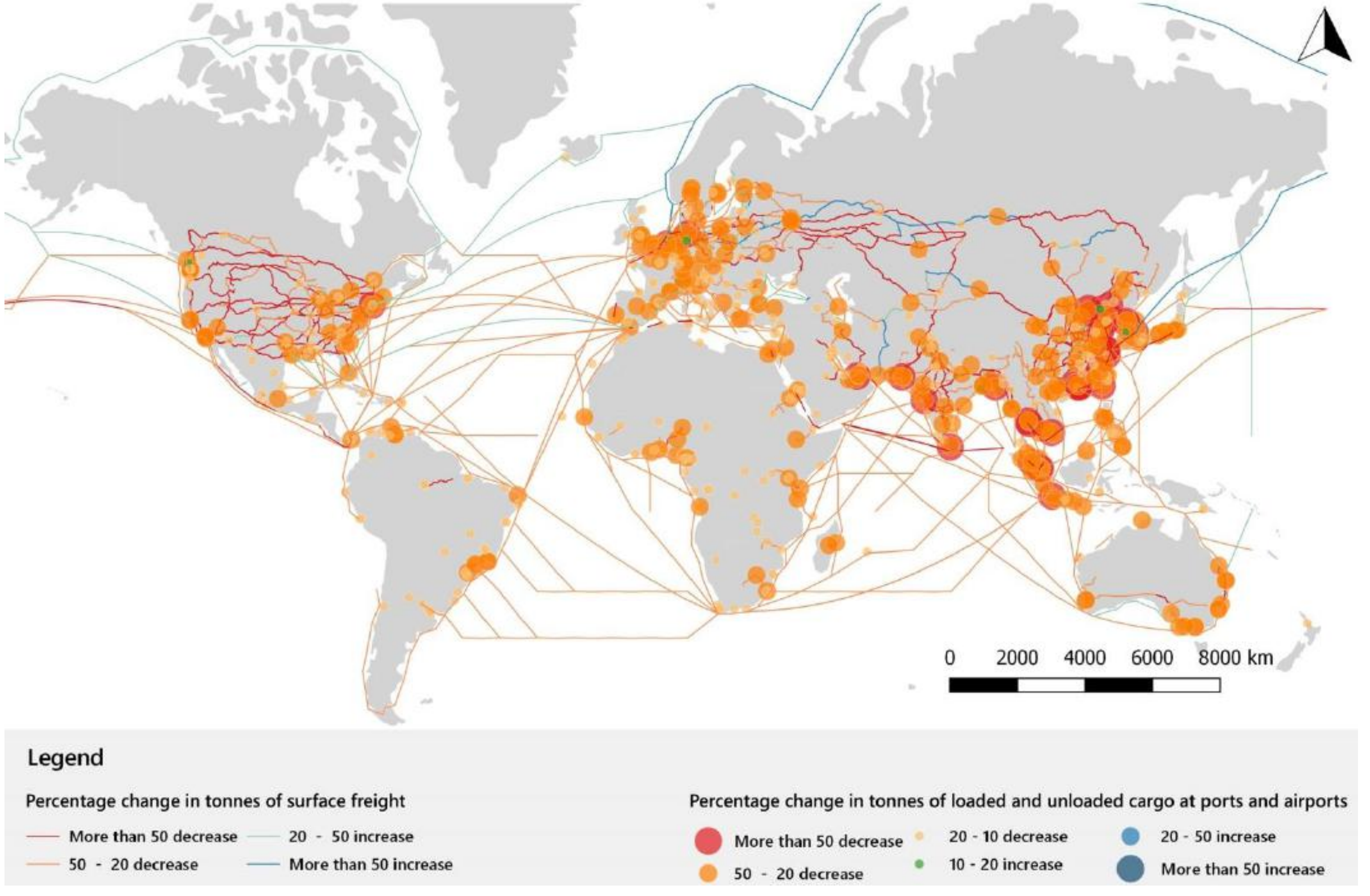

Table 5.7. Assumptions for disruptive scenarios for freight transport

Potential disruptions	Assumptions for non-disruptive scenario	Assumptions for disruptive scenario
E-commerce	Urban freight sees additional 5% demand increase compared to current ambitions in more developed regions by 2050	Urban freight sees an additional 25% demand increase compared to current ambitions in more developed regions by 2050 and 10% on other regions. Inter-urban freight increases by a quarter of urban values.
3D printing	No change from current uptake rate	Decrease of 38% in overall value of trade by 2050 compared to international trade forecasts employed in current and high ambition scenarios. Differentiated decreases by commodity types.
New trade routes	Planned improvements to infrastructure in central Asia region. Improved conditions for Europe-Asia connections through the Artic (but still with capacity and speed restrictions).	Planned infrastructure improvements in Central Asia are implemented. Travel times improve, capacity increases and transport costs (rail) decrease on two corridors connecting East Asia to Europe. Border crossing times shorten along these routes. Regular shipping connections between Asia and Europe through the Artic exist by 2030. The Artic also opens to Asia to North American routes in 2030, but with higher costs than regular shipping connections. Infrastructure quality improves in Africa, with shorter travel times and lower costs.
Energy transition in long distance heavy freight	Technological assumptions in line with the IEA-NPS (IEA, 2018a)	37% of heavy truck t-km powered by alternative fuels by 2050. Costs are initially higher than for conventional fuels but become lower by 2050. Differences in uptake and costs exist by region.
Autonomous trucks	No change from current uptake level	Up to 90% uptake by 2050 on inter-urban routes in some regions (Europe, North America, China, Japan and South Korea). Uptake for urban freight is lower. Carbon intensity decreases 14% and costs 45% compared to current values.
High-capacity vehicles	5% of inter-urban road freight transported with high capacity vehicles. Truck loads increase 50% and costs fall 20% per tonne-kilometre where HCVs are adopted.	20% of inter-urban road freight transported with HCVs. Truck loads increase 50% and costs fall 20% per t-km where HCVs are adopted.

Table 5.8. Disruptive scenarios in freight transport

	Potentially disruptive developments		
Trends/Disruptions	Logistics	Technology	Full disruptions
E-commerce	Disruptive	Non-disruptive	Disruptive
3D printing	Disruptive	Non-disruptive	Disruptive
New trade routes	Disruptive	Non-disruptive	Disruptive

Energy transition in long distance heavy freight	Non-disruptive	Disruptive	Disruptive
Autonomous trucks	Non-disruptive	Disruptive	Disruptive
High-capacity vehicles	Non-disruptive	Disruptive	Disruptive
	Mitigation measures		
Trends/Disruptions	**Logistics**	**Technology**	**Full disruptions**
International coal and oil consumption	Coal use decreases 50% by 2035 Oil use decreases 33% by 2035	Coal use decreases 50% by 2035 Oil use decreases 33% by 2035	Coal use decreases 50% by 2035 Oil use decreases 33% by 2035
Efficiency improvements and electric vehicles	NPS-IEA	EV30@30-IEA	EV30@30-IEA
Logistics efficiency	EV30@30-IEA	NPS-IEA	EV30@30-IEA

Note: Refer to Table 5.7 for definitions of Disruptive and Non-disruptive assumptions

An increase in logistical efficiency and exogenous shocks *per se* are not able to globally reduce CO_2 emissions below 2015 levels by 2050. Yet they do curb the growth of freight transport activity significantly, by 28% to 2050 compared to the current ambition scenario, which contributes to reducing related carbon emissions by 25% compared to this baseline.

3D printing contributes most to reducing freight demand, and in the scenario that assumes this technology can be scaled up, the volume of international trade declines substantially compared to the current ambition scenario. Reduced movement of oil and coal also cuts back global trade volumes. Also adding to the decline, but less so, is the shortening of freight distances resulting from the new trade routes.

The reduction in transport flows is sharper for air and sea freight, modes more directly associated with international trade. In comparison with the current ambition scenario, transport volumes decline by 50% for air cargo and 35% for maritime freight. The major changes in transport activity volumes mentioned in the full disruptions scenarios have origin in the disruptions included in this logistic scenario.

Highly ambitious technological targets and related disruptions are able to curb emissions to a higher extent than logistical measures and exogenous shocks. Nonetheless, technology alone cannot reduce emissions by 2050 to levels equal or below 2015. In this scenario there is still a 22% increase in emissions from 2015 to 2050.

Besides overall emission decrease in line with the high ambition scenario, there are also important modal shifts, namely from rail and inland waterways towards road. The compounded effects of cost decreases of road freight due to a large-scale adoption of autonomous trucks, high capacity vehicles and low- or zero-emission trucks leads to a global 8% increase in road freight volumes compared to the current ambition scenario by 2050. Rail activity decreases by 12% and inland waterways by 2%.

Figure 5.22. Projected freight volumes by mode, 2030-50

All scenarios, billion tonne-kilometres

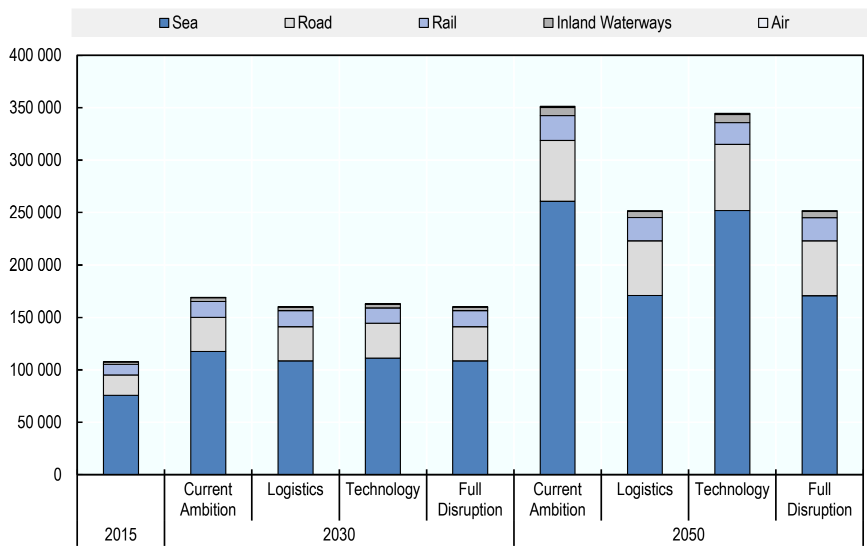

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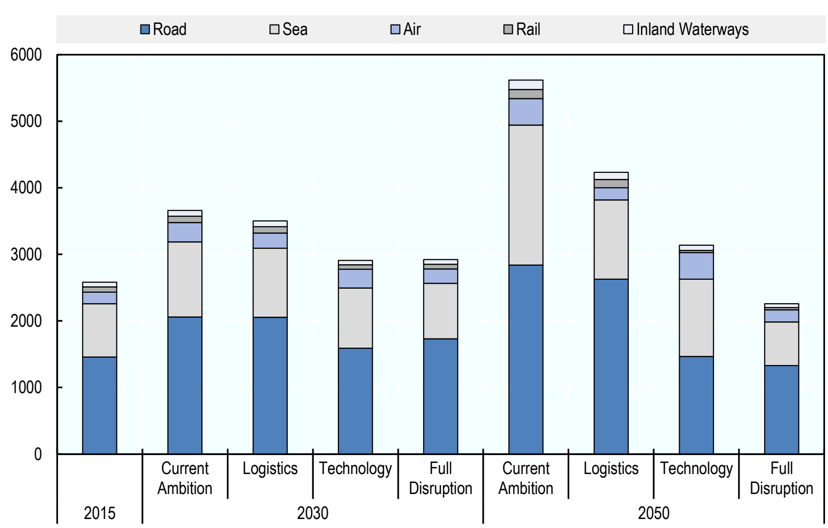
Figure 5.23. Projected CO_2 emissions from freight transport by mode, 2030-50

All scenarios, million tonnes

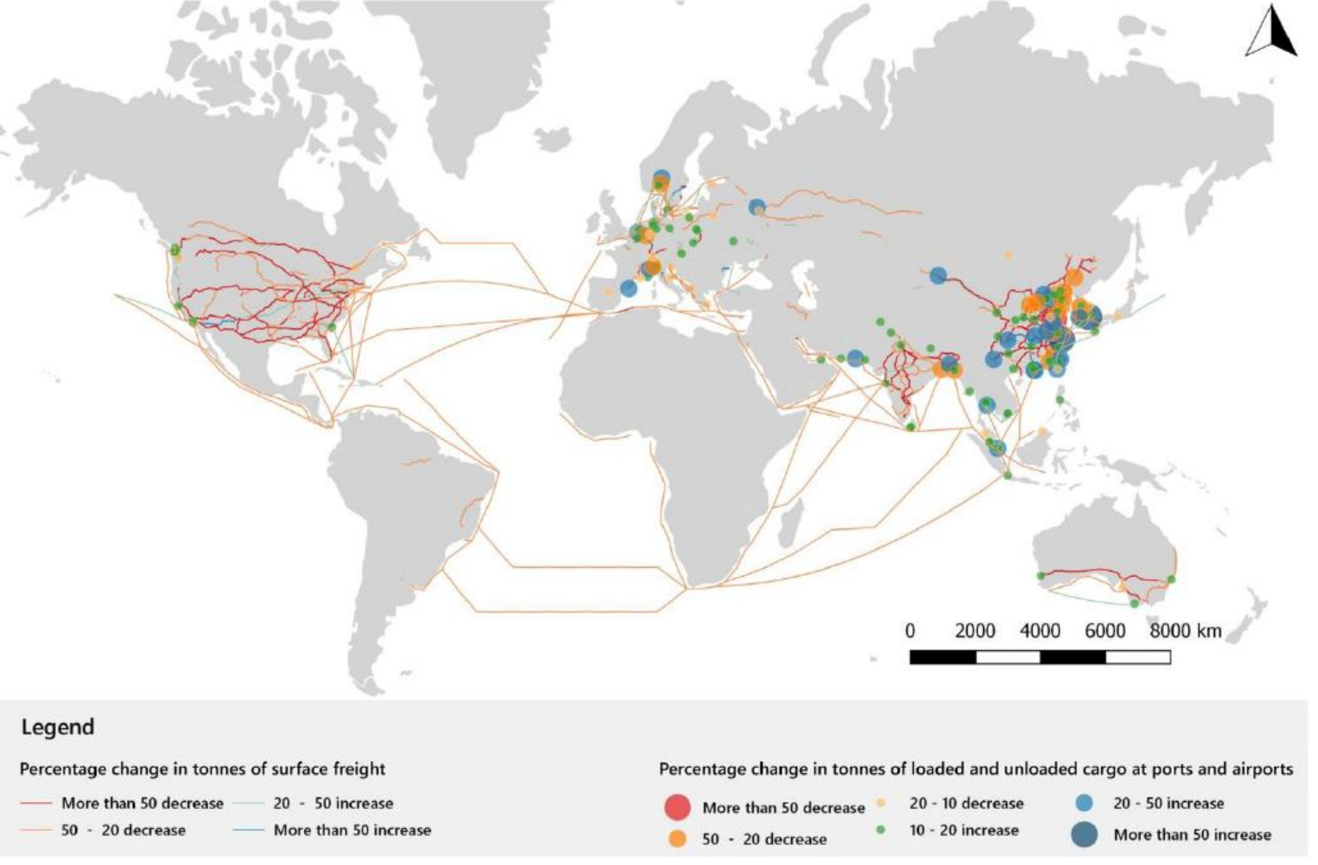


StatLink http://dx.doi.org/10.1787/888933973057

Regions with a relatively high share of rail freight tend to see greater modal shifts towards road. Rail activity in North America, for instance, suffers a 19% drop by 2050 compared to the current ambition scenario (Figure 5.24) while road freight volumes grow by 20%. China, India and Australia also see important increases in road share and decreases in rail activity. Air transport grows as well in this scenario, simply because there is a relative increase of higher value to density commodities that favour air transport.

Figure 5.24. Shift in transport flows in the technology scenario by 2050

Percentage change in tonnes compared to current ambition scenario



Notes

[1] Many B2B transactions do not necessarily impact transport, either because they do not change previous transport patterns in a significant way or, as is increasingly the case, because they do not involve the transportation of any goods at all (e.g. web development or other digital services).

[1] The substitutability or complementarity between online and in-store purchasing may also vary according to product type and frequency of purchase. However, while consumption-related e-commerce has an uncertain net impact on travel, service-related e-commerce is likely to decrease travel (European Commission, 2001).

[1] The Kra Canal would supplement current flows through the Strait of Malacca, the world's busiest maritime corridor. However, plans for its construction have never materialised over the course of the past century, due to financial costs and environmental concerns. Recently, China and Thailand have explored the idea at conferences in 2017 and 2018.

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Statistical annex

Rail freight transport

Million tonne-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	66	50	25	23	40	23	..	..
Armenia	743 e	816 e	867 e	851 e	786	640	658	690
Australia	258 624	261 420 e	290 570 e	319 000	367 700	401 600	..	..
Austria	19 833	20 345	19 499	19 564	20 746	20 814	21 361	22 256
Azerbaijan	8 250	7 845	8 212	7 958	7 371	6 210	5 192	4 633
Belarus	46 224	47 384 e	48 475 e	43 143 e	..	..	..	..
Belgium	6 264 e	6 698 e	..	..	..	..	..	..
Bosnia-Herzegovina	877	1 018	1 150	1 243	..	..	..	..
Bulgaria	3 064	3 291	2 908	3 246	3 439	3 650	3 434	3 931
Canada	240 292	248 468	256 622	258 617	277 402	282 780	276 159	289 910 p
China	2 764 413	2 946 579	2 918 709	2 917 390	2 753 020	2 375 430	2 379 230	..
Croatia	2 618	2 438	2 332	2 086	2 119	2 183	2 160	2 592
Czech Republic	13 770	14 316	14 266	13 965	14 574	15 261	15 619	15 843
Denmark	2 240	2 614	2 278	2 448	2 453	2 603	2 575	..
Estonia	6 638	6 271	5 129	4 722	3 256	3 114	2 339	2 325
Finland	9 750	9 395	9 275	9 470	9 596	8 468	9 455	10 362
France	29 965	34 202	32 539	32 230	32 596	34 252	32 569	33 442
Georgia	6 228	6 055	5 976	5 526	4 988	4 261	3 424	2 963
Germany	107 317	113 317	110 065	112 613	112 629	116 632	116 164	112 232
Greece	601	352	283 e	238 e	343 e	294	254	..
Hungary	8 809	9 118	9 230	9 722	10 158	10 010	10 528	11 053
Iceland	x	x	x	x	x	x	x	x
India	625 723	667 607	649 645	665 810	681 696	654 481	620 175 e	654 285 e
Ireland	92	105	91	99	100	96	101	100
Italy	18 616	19 787	20 244	19 037	20 157	20 781	22 712	..
Japan	20 398	19 998	20 471	21 071	21 029	21 519	21 265	..
Korea	9 452	9 997	10 271	10 459	9 564	9 749	8 414	8 229
Latvia	17 179	21 410	21 867	19 532	19 441	18 906	15 873	15 014
Liechtenstein	11	10	10	9	..	..	..	..
Lithuania	13 431	15 088	14 172	13 344	14 307	14 036	13 790	15 414
Luxembourg	309	270	231	218	208	207	..	..
Malta	x	x	x	x	x	x	x	x
Mexico	78 771	79 729	79 353	77 717	80 683	83 401	84 694	86 332
Moldova, Republic of	959	1 196	960	1 227	1 182	963	790	987
Montenegro, Republic of	151	136	73	105	94	112	112	169
Netherlands	5 925	6 378	6 142	6 077	6 170	6 472	6 641	6 467
New Zealand	3 919	4 178	4 581	4 547	4 492	4 450	4 258	3 882
North Macedonia	525	479	423	421	411	278	222	277
Norway	3 498 |	3 574	3 489	3 383	3 539	3 498	3 668	4 040
Poland	48 795	53 746	48 903	50 881	50 073	50 603	50 650	54 797
Portugal	2 313	2 322	2 421	2 290	2 438	2 661	2 622	2 742
Romania	12 375	14 719	13 472	12 941	12 264	13 673	13 535	13 782
Russian Federation	2 011 308	2 127 835	2 222 389	2 196 217	2 300 532	2 305 945	2 344 087	2 493 428
Serbia, Republic of	3 522	3 611	2 769	3 022	2 988	3 248	3 087	3 288
Slovak Republic	8 105	7 960	7 591	8 494	8 829	8 439	9 111	8 486
Slovenia	3 421	3 752	3 470	3 799	4 110	4 175	4 360	5 128
Spain	8 577	9 593	9 390	9 366	10 303	10 812	10 644	..
Sweden	23 464	22 864	22 043	20 970	21 296	20 699	21 406	21 838
Switzerland	11 074	11 526	11 061	11 812	12 313	12 431	12 447	11 665
Turkey	11 462	11 677	11 670	11 177	11 992	10 474	11 661	..
Ukraine	218 091	243 866	237 722	224 434 e	..	..	..	..
United Kingdom	18 576	20 974	21 467	22 401	22 143	19 342	17 053	17 167
United States	2 491 450	2 524 667	2 500 300	2 541 355	2 703 894 |	2 551 330	2 326 216	2 448 480

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Road freight transport

Million tonne-kilometres

<table>
<tr><th></th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th></tr>
<tr><td>Albania</td><td>4 626 e</td><td>3 805 e</td><td>3 223 e</td><td>3 497 e</td><td>..</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>Armenia</td><td>236</td><td>287</td><td>401</td><td>484</td><td>544</td><td>479</td><td>676</td><td>725</td></tr>
<tr><td>Australia</td><td>184 330</td><td>188 434</td><td>193 035</td><td>199 344</td><td>205 735</td><td>212 010</td><td>..</td><td>..</td></tr>
<tr><td>Austria</td><td>16 539</td><td>16 997</td><td>16 143</td><td>15 524</td><td>16 605</td><td>17 161</td><td>18 091</td><td>18 400</td></tr>
<tr><td>Azerbaijan</td><td>11 728</td><td>12 776</td><td>13 744</td><td>14 575</td><td>14 989</td><td>16 038</td><td>16 486</td><td>16 864</td></tr>
<tr><td>Belarus</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>Belgium</td><td>35 001</td><td>33 107</td><td>32 105</td><td>32 795</td><td>31 808</td><td>31 729</td><td>30 873</td><td>..</td></tr>
<tr><td>Bosnia-Herzegovina</td><td>..</td><td>1 718</td><td>2 310</td><td>2 658</td><td>..</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>Bulgaria</td><td>19 454</td><td>21 212</td><td>24 387</td><td>27 237</td><td>27 922</td><td>32 350</td><td>35 402</td><td>35 185</td></tr>
<tr><td>Canada</td><td>135 294</td><td>136 393</td><td>143 043</td><td>143 921</td><td>160 561</td><td>168 181</td><td>172 373 p</td><td>..</td></tr>
<tr><td>China</td><td>4 338 967</td><td>5 137 474</td><td>5 953 486</td><td>5 573 810</td><td>5 684 690</td><td>5 795 570</td><td>6 108 010</td><td>..</td></tr>
<tr><td>Croatia</td><td>8 780</td><td>8 927</td><td>8 649</td><td>9 133</td><td>9 381</td><td>10 439</td><td>11 337</td><td>11 833</td></tr>
<tr><td>Czech Republic</td><td>51 833</td><td>54 830</td><td>51 228</td><td>54 893</td><td>54 092</td><td>58 714</td><td>50 315</td><td>44 274</td></tr>
<tr><td>Denmark</td><td>10 573</td><td>12 025</td><td>12 292</td><td>12 222</td><td>12 950</td><td>12 324</td><td>12 943</td><td>..</td></tr>
<tr><td>Estonia</td><td>5 611</td><td>5 913</td><td>5 793</td><td>5 987</td><td>6 292</td><td>6 259</td><td>6 717</td><td>6 189</td></tr>
<tr><td>Finland</td><td>30 337</td><td>26 917</td><td>25 458</td><td>24 429</td><td>23 401</td><td>24 486</td><td>26 853</td><td>27 977</td></tr>
<tr><td>France</td><td>174 409</td><td>177 993</td><td>165 808</td><td>165 315</td><td>159 530</td><td>148 713</td><td>151 213</td><td>162 615</td></tr>
<tr><td>Georgia</td><td>620</td><td>628</td><td>637</td><td>646</td><td>655</td><td>664</td><td>674</td><td>683</td></tr>
<tr><td>Germany</td><td>313 097</td><td>323 848</td><td>307 106</td><td>305 781</td><td>310 142</td><td>314 816</td><td>315 768</td><td>313 143</td></tr>
<tr><td>Greece</td><td>20 146 e</td><td>20 426</td><td>20 416</td><td>19 203 p</td><td>19 223</td><td>19 763</td><td>..</td><td>..</td></tr>
<tr><td>Hungary</td><td>33 720</td><td>34 529</td><td>33 735</td><td>35 817</td><td>37 517</td><td>38 352</td><td>40 006</td><td>39 687</td></tr>
<tr><td>Iceland</td><td>806 e</td><td>777 e</td><td>786 e</td><td>808 e</td><td>850 e</td><td>907 e</td><td>1 052</td><td>..</td></tr>
<tr><td>India</td><td>1 287 300</td><td>1 407 800</td><td>1 508 000</td><td>1 653 600</td><td>1 824 300</td><td>2 026 100</td><td>2 226 570 e</td><td>2 435 870 e</td></tr>
<tr><td>Ireland</td><td>10 924</td><td>9 941</td><td>9 895</td><td>9 138</td><td>9 772</td><td>9 844</td><td>11 564</td><td>11 759</td></tr>
<tr><td>Italy</td><td>162 509</td><td>135 148</td><td>118 100</td><td>120 161</td><td>110 411</td><td>110 459</td><td>106 581</td><td>..</td></tr>
<tr><td>Japan</td><td>246 175 |</td><td>233 956</td><td>209 956</td><td>214 092</td><td>210 008</td><td>204 316</td><td>210 314</td><td>210 829</td></tr>
<tr><td>Korea</td><td>102 808</td><td>104 476</td><td>108 365</td><td>118 582</td><td>124 650</td><td>132 382</td><td>135 259</td><td>..</td></tr>
<tr><td>Latvia</td><td>10 590</td><td>12 131</td><td>12 178</td><td>12 816</td><td>13 670</td><td>14 690</td><td>14 227</td><td>14 972</td></tr>
<tr><td>Liechtenstein</td><td>305</td><td>312</td><td>281</td><td>318</td><td>..</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>Lithuania</td><td>19 398</td><td>21 512</td><td>23 449</td><td>26 338</td><td>28 067</td><td>26 485</td><td>30 974</td><td>39 099</td></tr>
<tr><td>Luxembourg</td><td>8 657</td><td>8 837</td><td>6 550</td><td>7 214</td><td>7 912</td><td>7 095</td><td>..</td><td>..</td></tr>
<tr><td>Malta</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>Mexico</td><td>220 285 |</td><td>226 900</td><td>233 464</td><td>235 427</td><td>239 710</td><td>245 136</td><td>251 122</td><td>256 136</td></tr>
<tr><td>Moldova, Republic of</td><td>3 233</td><td>3 597</td><td>3 954</td><td>4 423</td><td>4 306</td><td>4 217</td><td>4 693</td><td>5 008</td></tr>
<tr><td>Montenegro, Republic of</td><td>167</td><td>102</td><td>76</td><td>67</td><td>122 |</td><td>140</td><td>121</td><td>103</td></tr>
<tr><td>Netherlands</td><td>30 114</td><td>30 344</td><td>28 718</td><td>31 845</td><td>32 033</td><td>32 075</td><td>33 953</td><td>32 960</td></tr>
<tr><td>New Zealand</td><td>20 050</td><td>20 534</td><td>20 944</td><td>21 286</td><td>23 301</td><td>23 290 |</td><td>23 313</td><td>25 293</td></tr>
<tr><td>North Macedonia</td><td>4 235</td><td>8 933 |</td><td>8 965</td><td>7 466</td><td>10 622</td><td>10 192</td><td>10 590</td><td>10 850</td></tr>
<tr><td>Norway</td><td>17 334 |</td><td>17 167</td><td>18 086</td><td>19 712</td><td>20 297</td><td>19 730</td><td>19 676</td><td>..</td></tr>
<tr><td>Poland</td><td>214 204</td><td>218 888</td><td>233 310</td><td>259 708</td><td>262 860</td><td>273 107</td><td>303 560</td><td>348 559</td></tr>
<tr><td>Portugal</td><td>34 640</td><td>37 472</td><td>32 274</td><td>39 624</td><td>36 336</td><td>32 525</td><td>34 683</td><td>..</td></tr>
<tr><td>Romania</td><td>25 883</td><td>26 347</td><td>29 662</td><td>34 026</td><td>35 135</td><td>39 022</td><td>48 175</td><td>54 704</td></tr>
<tr><td>Russian Federation</td><td>199 341</td><td>222 823</td><td>248 862</td><td>250 054</td><td>246 784</td><td>232 549</td><td>232 873</td><td>236 431</td></tr>
<tr><td>Serbia, Republic of</td><td>1 689</td><td>1 907</td><td>2 474</td><td>2 824</td><td>2 959</td><td>2 973</td><td>4 299</td><td>4 980</td></tr>
<tr><td>Slovak Republic</td><td>27 411</td><td>29 045</td><td>29 504</td><td>30 005</td><td>31 304</td><td>33 525</td><td>36 106</td><td>35 362</td></tr>
<tr><td>Slovenia</td><td>2 289</td><td>2 176</td><td>1 849</td><td>1 889</td><td>2 062</td><td>2 069</td><td>2 135</td><td>2 311</td></tr>
<tr><td>Spain</td><td>210 064</td><td>206 840</td><td>199 205</td><td>192 594</td><td>195 763</td><td>209 387</td><td>216 993</td><td>231 105</td></tr>
<tr><td>Sweden</td><td>32 738</td><td>33 417</td><td>37 305 |</td><td>38 629</td><td>38 808</td><td>38 102</td><td>39 273</td><td>38 553</td></tr>
<tr><td>Switzerland</td><td>16 906</td><td>17 372</td><td>17 109</td><td>17 241</td><td>17 541</td><td>17 214</td><td>16 963</td><td>..</td></tr>
<tr><td>Turkey</td><td>190 365</td><td>203 072</td><td>216 123</td><td>224 048</td><td>234 492</td><td>244 329</td><td>253 139</td><td>262 739</td></tr>
<tr><td>Ukraine</td><td>34 391</td><td>38 596</td><td>38 951</td><td>..</td><td>..</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>United Kingdom</td><td>153 829</td><td>150 091 |</td><td>152 706</td><td>140 874</td><td>136 873</td><td>151 805</td><td>157 657</td><td>156 066</td></tr>
<tr><td>United States</td><td>3 668 077</td><td>3 859 535</td><td>2 760 511 |</td><td>2 833 848</td><td>2 910 390</td><td>2 923 659</td><td>2 953 348</td><td>..</td></tr>
</table>

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Inland waterway freight transport

Million tonne-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	..	..	..	..	..	..	..	..
Armenia	x	x	x	x	x	x	x	x
Australia	x	x	x	x	x	x	x	x
Austria	2 375	2 123	2 191	2 353	2 177	1 806	1 962	2 022
Azerbaijan	x	x	x	x	x	x	x	x
Belarus	..	..	..	..	..	..	..	..
Belgium	8 210	9 251 e	10 420	10 365	10 451	10 426	10 331	11 098
Bosnia-Herzegovina	x	x	x	x	x	x	x	x
Bulgaria	1 813	1 422	1 397	1 196	971	1 081	1 255	1 202
Canada	23 934	25 000 e	26 300 e	26 600 e	..	..	..	..
China	2 242 853	2 606 884	2 829 548	3 073 028	3 683 960	3 753 650	3 926 380	..
Croatia	941	692	772	771	716	879	836	813
Czech Republic	679	695	669	693	656	585	620	623
Denmark	x	x	x	x	x	x	x	x
Estonia	x	x	x	x	x	x	x	x
Finland	76	90	124	121	136	130	103	120
France	8 060	7 864	7 830	7 912	7 752	7 461	6 836	6 715
Georgia	x	x	x	x	x	x	x	x
Germany	62 278	55 027	58 488	60 070	59 093	55 315	54 347	55 518
Greece	x	x	x	x	x	x	x	x
Hungary	2 393	1 840	1 982	1 924	1 811	1 824	1 975	1 992
Iceland	x	x	x	x	x	x	x	x
India	4 030	3 800	3 063	2 418	2 847	3 450	3 952	4 347 e
Ireland	x	x	x	x	x	x	x	x
Italy	135	144	81	89	64	62	67	..
Japan	x	x	x	x	x	x	x	x
Korea	x	x	x	x	x	x	x	x
Latvia	0	0	0	0	0	0	0	0
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	4	4	2	1	1	1	1	1
Luxembourg	359	305	290	315	285	235	..	..
Malta	x	x	x	x	x	x	x	x
Mexico	x	x	x	x	x	x	x	x
Moldova, Republic of	0	1	1	1	1	0	0	0
Montenegro, Republic of	x	x	x	x	x	x	x	x
Netherlands	46 592	47 303	47 520	48 600	48 535	49 425	48 799	48 998
New Zealand	x	x	x	x	x	x	x	x
North Macedonia	x	x	x	x	x	x	x	x
Norway	x	x	x	x	x	x	x	x
Poland	1 030	909	815	768	779	2 187	832	877
Portugal	..	..	..	..	..	..	..	..
Romania	14 317	11 409	12 520	12 242	11 760	13 168	13 153	12 517
Russian Federation	53 955	59 144	80 762 |	80 101	72 317	63 620	29 042	31 292
Serbia, Republic of	875	963	605	701	759	859	926	725
Slovak Republic	1 189	931	986	1 006	905	741	903	933
Slovenia	x	x	x	x	x	x	x	x
Spain	x	x	x	x	x	x	x	x
Sweden	..	..	..	..	..	..	16	12
Switzerland	..	..	..	..	..	..	..	..
Turkey	x	x	x	x	x	x	x	x
Ukraine	3 837	2 218	1 748	..	..	..	..	..
United Kingdom	125	143	157	211	169	120	108	99
United States	450 529	464 667	461 927	438 253	482 977	458 262	..	..

.. Not available; | Break in series; e Estimated value; x Not applicable

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Oil pipeline transport

Million tonne-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	2	..	..	..	..	..	..	..
Armenia	2 103 e	2 470 e	2 876 e	2 750 e	2 837	2 624	2 550	2 835
Australia	x	x	x	x	x	x	x	x
Austria	7 000	7 228	7 146	8 392	8 259	8 475	8 473	8 396
Azerbaijan	72 931	65 850	63 172	63 734	67 039	67 515	65 924	65 879
Belarus	x	x	x	x	x	x	x	x
Belgium	1 450	1 450	..	..	..	..	..	..
Bosnia-Herzegovina	x	x	x	x	x	x	x	x
Bulgaria	415	481	573	633	583	661	710	706
Canada	124 300	151 200	165 000	175 400	192 400	213 600	..	..
China	219 719	288 544	321 100	349 600	432 800	466 500	419 600	..
Croatia	1 703	1 477	1 216	1 485	1 447	1 740	1 921	2 111
Czech Republic	2 191	1 954	1 907	1 933	2 063	2 023	1 588	2 165
Denmark	3 547	3 265	3 078	2 739	2 409	2 258	2 026	..
Estonia	x	x	x	x	x	x	x	x
Finland	x	x	x	x	x	x	x	x
France	17 607	17 207	15 151	11 521	11 055	11 443	11 373	11 181
Georgia	..	..	..	..	..	..	..	..
Germany	16 259	15 623	16 207	18 180	17 541	17 714	18 761	18 239
Greece	x	x	x	x	x	x	x	x
Hungary	5 623	5 581	5 802	5 694	5 801	5 305	5 850	7 430
Iceland	x	x	x	x	x	x	x	x
India	123 060	134 800	141 660	..	..	..	..	..
Ireland	x	x	x	x	x	x	x	x
Italy	10 400	9 954	10 066	10 024	9 555	9 213	9 977	10 258 p
Japan	x	x	x	x	x	x	x	x
Korea	x	x	x	x	x	x	x	x
Latvia	2 350	2 439	2 631	2 279	2 376	1 965	1 507	1 411
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	579	591	632	563	567	496	406	391
Luxembourg	x	x	x	x	x	x	x	x
Malta	x	x	x	x	x	x	x	x
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	x	x	x	x	x	x	x	x
Montenegro, Republic of	x	x	x	x	x	x	x	x
Netherlands	5 647	5 502	5 572	5 405	5 837	6 044	6 047	6 143
New Zealand	x	x	x	x	x	x	x	x
North Macedonia	123	98	37	..	6 |	6	10	13
Norway	3 465	3 372	3 115	2 724	2 845	3 377	3 813	..
Poland	24 157	23 461	22 325	20 112	20 543	21 843	22 204	21 080
Portugal	383	364	360	350	371	391	392	..
Romania	996	879	785	829	984	1 029	1 131	1 087
Russian Federation	1 122 964	1 120 140	1 187 627	1 223 931	1 220 442	1 268 535	1 308 126	1 315 268
Serbia, Republic of	381	311	295	381	355	405	447	481
Slovak Republic	..	..	..	..	..	..	..	..
Slovenia	x	x	x	x	x	x	x	x
Spain	8 182	8 601	8 900	8 691	8 967	10 115	9 990	9 713
Sweden	x	x	x	x	x	x	x	x
Switzerland	218	203	183	228	234	113 |	109	107
Turkey	39 578	44 704	37 433	26 756	17 106	52 514	52 683	..
Ukraine	18 688	14 292	10 607	..	..	..	..	..
United Kingdom	10 309	10 024	9 914	..	..	..	..	..
United States	831 308	881 385	..	..	..	..	..	..

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Total inland freight transport

Million tonne-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	4 694	3 855 |	3 248	3 520	..	..	..	..
Armenia	3 082 e	3 573 e	4 144 e	4 085 e	4 167	3 743	3 883	4 256
Australia	442 954	449 854 e	483 605 e	518 344	573 435	613 610	..	..
Austria	45 747	46 693	44 979	45 833	47 787	48 256	49 887	51 074
Azerbaijan	92 909	86 471	85 128	86 267	89 399	89 763	87 602	87 376
Belarus	..	..	..	..	..	..	..	..
Belgium	50 925 e	50 506 e	..	..	..	..	..	..
Bosnia-Herzegovina	..	2 736	3 460	3 901	..	..	..	..
Bulgaria	24 746	26 406	29 265	32 312	32 915	37 742	40 801	41 024
Canada	523 820	561 061	590 965	604 538	630 363	664 561 p	..	..
China	9 565 952	10 979 481	12 022 843	11 913 828	12 554 470	12 391 150	12 833 220	..
Croatia	14 042	13 534	12 969	13 475	13 663	15 241	16 254	17 349
Czech Republic	68 473	71 795	68 070	71 484	71 385	76 582	68 141	62 904
Denmark	16 360	17 904	17 648	17 409	17 812	17 185	17 544	..
Estonia	12 249	12 184	10 922	10 709	9 548	9 373	9 056	8 514
Finland	40 163	36 402	34 857	34 020	33 133	33 084	36 411	38 459
France	230 041	237 266	221 328	216 978	210 933	201 869	201 991	213 952
Georgia	..	..	..	..	..	..	..	..
Germany	498 951	507 815	491 866	496 644	499 405	504 477	505 040	499 132
Greece	20 747 e	20 778 e	20 699 e	19 441 e	19 566 e	20 057	..	..
Hungary	50 545	51 068	50 749	53 157	55 287	55 490	58 359	60 162
Iceland	806 e	777 e	786 e	808 e	850 e	907 e	1 052	..
India	2 040 113	2 214 007	2 302 368	2 321 828	2 508 843	2 684 031	2 850 697 e	3 094 502 e
Ireland	11 016	10 046	9 986	9 237	9 872	9 940	11 665	11 859
Italy	191 660	165 033	148 491	149 311	140 187	140 515	139 337	..
Japan	266 573 |	253 954	230 427	235 163	231 037	225 835	231 579	..
Korea	112 260	114 473	118 636	129 041	134 214	142 131	143 673	..
Latvia	30 119	35 980	36 676	34 627	35 487	35 561	31 607	31 397
Liechtenstein	316	322	291	327	..	..	..	..
Lithuania	33 412	37 195	38 255	40 246	42 942	41 018	45 171	54 905
Luxembourg	9 325 e	9 412 e	7 071 e	7 747 e	8 405	7 537	..	..
Malta	..	..	..	..	..	..	..	..
Mexico	299 056 |	306 629	312 817	313 144	320 393	328 537	335 816	342 468
Moldova, Republic of	4 192	4 794	4 915	5 651	5 489	5 180	5 483	5 995
Montenegro, Republic of	318	238	149	172	216 |	252	233	272
Netherlands	88 278	89 527	87 952	91 927	92 575	94 016	95 440	94 568
New Zealand	23 969	24 712	25 525	25 833	27 793	27 740 |	27 571	29 175
North Macedonia	4 883	9 510 |	9 425	7 887 |	11 039 |	10 476	10 822	11 140
Norway	24 297 |	24 113	24 690	25 819	26 681	26 605	27 157	..
Poland	288 186	297 004	305 353	331 469	334 255	347 740	377 246	425 313
Portugal	37 336	40 158	35 055	42 264	39 145	35 577	37 697	..
Romania	53 571	53 354	56 439	60 038	60 143	66 892	75 994	82 090
Russian Federation	3 387 568	3 529 942	3 739 640 |	3 750 303	3 840 075	3 870 649	3 914 128	4 076 419
Serbia, Republic of	6 467	6 792	6 143	6 928	7 061	7 485	8 759	9 474
Slovak Republic	36 705	37 936	38 081	39 505	41 038	42 705	46 120	44 781
Slovenia	5 710	5 928	5 319	5 688	6 172	6 244	6 495	7 439
Spain	226 823	225 034	217 495	210 651	215 033	230 314	237 627	..
Sweden	56 202	56 281	59 348 |	59 599	60 104	58 801	60 695 |	60 403
Switzerland	28 198	29 101	28 353	29 281	30 088	29 758	29 519	..
Turkey	241 405	259 453	265 226	261 981	263 590	307 317	317 483	..
Ukraine	275 007	298 972	289 028	..	..	..	..	..
United Kingdom	182 839	181 231 |	184 244	163 486	159 185	171 268	174 818	173 332
United States	7 441 364	7 730 254	..	..	..	..	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Coastal shipping

National transport

Million tonne-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	..	..	..	..	..	..	..	..
Armenia	x	x	x	x	x	x	x	x
Australia	116 208	113 357	102 577	104 462	105 404	105 245	..	..
Austria	x	x	x	x	x	x	x	x
Azerbaijan	4 859	5 186	5 062	4 632	4 124	2 937	3 002	4 418
Belarus	x	x	x	x	x	x	x	x
Belgium	..	..	..	..	..	..	..	..
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	..	..	..	..	..	..	..	..
Canada	29 547	31 735	..	..	..	..	..	..
China	4 599 900	4 935 500	5 341 200	4 870 500	5 593 500	5 423 600	5 807 500	..
Croatia	210	217	222	211	205	217	212	208
Czech Republic	x	x	x	x	x	x	x	x
Denmark	..	..	..	..	..	..	..	..
Estonia	0	0	0	0	0	1	0	0
Finland	3 621	3 966	2 840	1 900	2 010	2 180	2 170	2 270
France	..	..	..	..	..	..	..	..
Georgia	..	..	..	..	..	..	..	..
Germany	..	..	..	..	..	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	x	x	x	x	x	x	x	x
Iceland	47	43	12	32	13	30	23	..
India	..	..	..	..	..	..	..	..
Ireland	..	..	..	..	..	..	..	..
Italy	53 156 e	53 708 e	50 287	49 112	52 867	51 179	56 713 e	58 098 e
Japan	179 898	174 900	177 791	184 860	183 120	180 381	180 438	180 934
Korea	23 281	27 220	25 804	30 476	29 900	31 841	37 036	..
Latvia	..	..	..	..	..	..	..	..
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	x	x	x	x	x	x	x	x
Luxembourg	x	x	x	x	x	x	x	x
Malta	..	..	..	..	..	..	..	..
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	x	x	x	x	x	x	x	x
Montenegro, Republic of	x	x	x	x	x	x	x	x
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	x	x	x	x	x	x	x	x
Norway	21 463	23 625	25 642	22 649	21 941	23 899	24 340	..
Poland	..	..	..	..	..	..	..	..
Portugal	..	..	..	..	..	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	12 640	13 239	12 138 |	12 133	13 126	14 956	12 944	12 299
Serbia, Republic of	x	x	x	x	x	x	x	x
Slovak Republic	x	x	x	x	x	x	x	x
Slovenia	..	..	..	..	..	..	..	..
Spain	41 666	42 811	41 761	40 773	41 848	44 536	47 488	47 986 p
Sweden	7 851	7 794 |	6 892	6 764	6 663	6 814	6 610	6 799
Switzerland	x	x	x	x	x	x	x	x
Turkey	12 569	15 961	17 158	19 725	18 553	19 189	19 492	22 087
Ukraine	..	2 747	1 702	..	..	..	..	..
United Kingdom	40 800	41 600	34 000	28 000	26 000	30 000	29 000	24 000
United States	280 822	263 105	229 349	239 158	251 801	256 376	250 690	..

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Rail container transport

Twenty-foot equivalent unit (TEU)

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	..	..	..	..	..	..	..	..
Armenia	..	..	..	..	15 735	..	..	..
Australia	..	..	..	..	..	..	..	..
Austria	1 310 989	1 356 994	1 278 267	1 237 076	1 296 064	1 445 960	1 532 708	1 725 083
Azerbaijan	13 582	16 797	19 264	17 396	10 041	12 475	12 682	20 315
Belarus	..	..	..	..	..	..	..	..
Belgium	..	..	..	..	..	..	..	..
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	57 297	51 387	53 272	63 725	35 419	37 807	46 527	35 580
Canada	3 235 761	3 315 391	3 559 595	3 686 321	3 897 973	4 071 322	4 170 821	4 534 111
China	..	..	..	..	..	..	..	..
Croatia	69 583	44 214	37 744	41 299	40 792	34 115	..	..
Czech Republic	1 051 439	1 111 464	1 157 228	1 274 125	1 336 973	1 476 907	1 548 782	1 492 392
Denmark	197 945	198 763	157 306	166 870	137 144	128 635	156 621	..
Estonia	22 484	34 967	48 863	62 014	72 019	42 995	53 947	40 058
Finland	70 204	60 174	43 105	42 211	41 137	33 434	33 552	40 987
France	..	..	..	..	..	..	..	213 952
Georgia	45 923	43 856	55 798	48 083	49 339	44 022	35 913	41 392
Germany	5 614 553	5 921 037	6 228 484	6 456 060	6 272 430	5 979 035	6 349 050	6 065 056
Greece	51 009	65 175	..	..	39 730	50 657	39 265	..
Hungary	568 685	520 752	386 746	519 480	448 166	651 093	736 798	458 169
Iceland	x	x	x	x	x	x	x	x
India	2 562 000	2 604 000	2 586 000	2 869 000	3 111 000	2 924 000	3 102 000	3 531 900
Ireland	13 472	14 280	13 776	14 784	15 330	14 910	15 876	17 009
Italy	649 259	563 196	752 433	767 503	789 217	710 969	730 452	811 785
Japan	..	..	..	..	..	..	..	..
Korea	..	..	..	..	..	..	..	..
Latvia	98 223	101 099	111 117	97 710	97 028	69 813	56 339	54 736
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	78 188	102 297	104 171	103 952	90 745	69 964	67 601	92 751
Luxembourg	..	..	..	..	..	..	..	..
Malta	x	x	x	x	x	x	x	x
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	1 914	1 774	1 463	2 015	1 883	365	1 080	807
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	921 108	939 808	1 539 810	1 300 000	1 406 000	1 441 000	1 600 000	1 377 000
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	..	..	..	..	..	..	..	..
Norway	493 386	412 043	386 620	332 653	324 815	322 765	304 327	399 477
Poland	569 759	783 338	1 026 181	1 091 888	1 072 627	1 098 698	1 353 936	1 619 943
Portugal	171 146	185 456	191 895	183 583	262 337	367 905	416 171	441 818
Romania	196 328	125 372	91 465	61 474	54 995	99 737	95 561	102 468
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	..	..	..	..	..	..	..	..
Slovak Republic	449 429	585 669	526 643	593 281	636 652	621 315	618 227	610 941
Slovenia	325 556	385 194	395 945	390 507	398 621	458 449	477 693	509 652
Spain	..	..	..	..	..	..	..	..
Sweden	536 934	486 271	450 303	433 918	430 588	411 664	388 772	394 523
Switzerland	..	..	..	..	..	..	..	..
Turkey	451 710	659 004	707 989	814 981	891 605	713 504	789 761	..
Ukraine	167 535	214 634	262 455	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; x Not applicable

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Maritime container transport

Twenty-foot equivalent unit (TEU)

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	71 614	80 744	87 909	109 054	99 350	104 060	..	..
Armenia	x	x	x	x	x	x	x	x
Australia	6 329 135	6 788 836	7 060 177	7 164 877	7 383 000 p	7 642 000 p	7 759 000 p	..
Austria	x	x	x	x	x	x	x	x
Azerbaijan	13 306	9 712	4 459	6 117	10 485	13 307	17 102	15 337
Belarus	x	x	x	x	x	x	x	x
Belgium	9 601 000	9 511 000	9 165 000	9 188 000	9 726 000	9 776 000	10 083 000	..
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	170 835	179 167	212 369	218 999	236 944	242 865	245 459	274 880
Canada	4 670 200	4 734 600	5 109 500	5 225 900	5 429 700	5 792 200	5 684 800	6 322 300
China	..	..	..	..	..	..	..	..
Croatia	144 649	154 451	144 041	130 236	138 278	181 912	208 133	245 559
Czech Republic	x	x	x	x	x	x	x	x
Denmark	734 000	782 000	763 000	747 000	743 000	750 000	764 000	..
Estonia	152 060	198 193	228 032	253 900	261 069	209 118	204 368	230 409
Finland	1 219 575	1 398 630	1 449 596	1 472 143	1 440 462	1 413 654	1 510 314	1 630 105
France	3 921 096	3 890 854	4 073 476	4 281 491	4 433 810	4 536 900	4 515 727	4 996 894
Georgia	226 115	299 461	357 654	403 447	446 972	379 816	329 805	394 787
Germany	13 096 000	15 271 000	15 325 000	15 552 000	15 905 000	15 181 000	15 205 000	15 129 000
Greece	1 187 487	2 054 064	3 220 371	3 620 126	3 928 785	3 744 380	4 131 533	4 512 982
Hungary	x	x	x	x	x	x	x	x
Iceland	..	..	..	..	..	..	..	..
India	7 561 000	7 651 000	7 714 000	7 453 000	7 960 000	8 148 000	8 442 000	9 139 000
Ireland	772 548	744 056	732 316	726 019	796 620	876 848	916 829	956 904
Italy	8 644 600	8 645 200	9 398 353	9 491 151	10 104 971	10 180 380	11 336 766	10 730 533 p
Japan	20 533 734	21 135 704	21 225 537	21 490 748	21 717 653	21 196 655	21 709 965	..
Korea	19 368 960	21 610 502	22 550 275	23 469 251	24 798 210	25 680 530	26 005 344	..
Latvia	208 508	246 590	366 824	385 665	391 218	359 756	388 484	450 071
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	295 226	382 194	381 371	402 733	450 183	350 393	441 664	474 209
Luxembourg	x	x	x	x	x	x	x	x
Malta	..	..	..	..	..	..	..	..
Mexico	3 691 374 |	4 223 631	4 878 097	4 875 281	5 058 635	5 506 488	5 680 484	..
Moldova, Republic of	x	x	x	x	x	x	x	x
Montenegro, Republic of	x	x	x	x	x	x	x	x
Netherlands	11 242 400	11 446 796	11 522 747	11 133 970	11 756 188	11 719 281	11 878 642	13 122 784
New Zealand	..	..	2 414 656	2 503 737	2 672 030	2 777 805	2 869 420	3 120 030
North Macedonia	x	x	x	x	x	x	x	x
Norway	656 244	691 172	714 565	729 947	761 332	770 347	735 229	777 557
Poland	1 041 690	1 330 746	1 648 886	1 979 703	2 256 061	1 793 407	2 306 343	2 256 442
Portugal	1 690 073	1 791 644	1 994 327	2 418 743	2 706 975	2 752 614	2 919 806	3 167 199
Romania	548 094	653 306	675 414	659 375	663 271	689 489	706 157	692 032
Russian Federation	2 454 838	3 028 264	3 371 039	3 501 985	3 617 159	2 906 555	3 056 806	3 520 306
Serbia, Republic of	x	x	x	x	x	x	x	x
Slovak Republic	x	x	x	x	x	x	x	x
Slovenia	480 981	586 915	556 392	596 429	676 381	802 696	845 547	919 652
Spain	12 505 803	13 849 935	13 999 337	13 709 523	14 066 730	14 252 380	15 130 479	15 771 021 p
Sweden	1 071 238	1 165 087	1 150 775	1 147 065	1 155 418	1 115 992	1 157 348	1 180 740
Switzerland	x	x	x	x	x	x	x	x
Turkey	5 743 455	6 523 506	7 192 396	7 899 933	8 351 122	8 146 398	8 761 974	10 010 536
Ukraine	659 690	729 523	693 210	..	..	..	..	..
United Kingdom	8 254 000	8 176 000	8 013 000	8 273 000	9 540 000	9 799 000	10 230 000	10 259 000
United States	31 507 445	32 745 592	33 236 967	34 484 687	35 867 974	35 665 402	36 504 338	..

.. Not available; | Break in series; x Not applicable; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Passenger transport by rail

Million passenger-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	19	18	16	12	8	7	..	..
Armenia	50 e	49 e	53 e	55 e	52	44	50	55
Australia	14 750	14 974	15 256	15 222	15 239	15 675	..	..
Austria	10 737	10 875	11 323	11 915	12 092	12 208	12 578	12 657
Azerbaijan	917	660	591	609	612	495	448	467
Belarus	7 578	7 941 e	8 977 e	8 998 e	..	..	..	..
Belgium	10 403	11 003	..	10 595	10 974 e	10 333 e	10 025 e	10 167 e
Bosnia-Herzegovina	59	100	54	40	..	..	..	..
Bulgaria	2 100	2 068	1 876	1 826	1 702	1 552	1 458	1 438
Canada	1 404	1 404	1 376	1 365	1 327	1 422	1 482	1 610 p
China	876 218	961 229	981 233	1 059 560	1 124 190	1 196 060	1 257 930	..
Croatia	1 742	1 486	1 104	948	927	951	836	745
Czech Republic	6 591	6 714	7 265	7 601	7 797	8 298	8 843	9 498
Denmark	6 577	6 890	7 020	7 076	6 808	6 808	6 653	..
Estonia	248	241	236	225	282	289	316	367
Finland	3 959	3 882	4 035	4 053	3 874	4 113 |	3 868	4 271
France	102 167	105 596	105 956	105 215	104 589	104 849	104 198	110 464
Georgia	654	641	625	585	550	465	545	597
Germany	83 886	85 414	88 796	89 615	90 976	91 603	95 465 p	..
Greece	1 337	958	832 e	755 e	1 072	1 263	1 192	..
Hungary	7 692	7 806	7 806	7 843	7 738	7 609	7 653	7 731
Iceland	x	x	x	x	x	x	x	x
India	978 508	1 046 522	1 098 103	1 140 412	1 147 190	1 143 039	1 149 835	1 161 333 e
Ireland	1 678	1 638	1 578	1 569	1 695	1 917	1 990	2 122
Italy	47 172	46 845	46 759	48 739	49 957	52 207	52 178	..
Japan	393 466	395 067	404 396	414 387	413 970	427 486	431 799	..
Korea	58 381	63 044	70 079	66 353	67 860	68 371	77 837	..
Latvia	749	741	725	729	649	591	584	596
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	373	389	403	391	373	361	396	424
Luxembourg	347	349	373	394	409	383	..	..
Malta	x	x	x	x	x	x	x	x
Mexico	844 |	891	970	1 036	1 150	1 411	1 481	1 550
Moldova, Republic of	399	363	347	330	257	181	122	99
Montenegro, Republic of	91	65	62	73	76	81	84	60
Netherlands	15 400	16 808	17 098	17 018	17 018	17 700 e	18 532	18 437
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	155	145	99	80	80	178	83	59
Norway	3 683	3 644	3 783	3 943	4 148	4 318	4 527	..
Poland	17 921	18 177	17 826	16 797	16 015	17 367	19 175	20 319
Portugal	4 111	4 143	3 803	3 649	3 852	3 957	4 146	4 391
Romania	5 438	5 073	4 571	4 411	4 976	5 149	4 988	5 663
Russian Federation	138 885	139 742	144 612	138 517	130 027	120 644	124 620	123 096
Serbia, Republic of	522	541	540	612	453	509	438	377
Slovak Republic	2 309	2 431	2 459	2 485	2 583	3 411	3 595	3 873
Slovenia	813	773	742	760	697	709	680	650
Spain	22 456	22 795	22 476	23 788	25 072	26 142	26 670	27 516
Sweden	11 155	11 378	11 792	11 842	12 121	12 741	12 924 p	13 331
Switzerland	19 177	19 471	19 262	19 447	20 010	20 389	20 812	..
Turkey	5 491	5 882	4 598	3 777	4 393	4 828	4 325	..
Ukraine	50 248	50 593	49 329	48 881 e	..	..	..	..
United Kingdom	64 657	67 995	69 774	72 109	75 399	77 613	79 668	80 238 p
United States	10 332	10 570	10 949	10 959	10 742	10 519	10 494	10 563

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Passenger transport by passenger car

Million passenger-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	5 535 e	6 726	6 654	7 587	..	..	..	..
Armenia	2 344	2 380	2 450	2 457	2 537	2 396	2 437	2 403
Australia	262 517	265 181	267 609	269 617	271 591	274 997	..	..
Austria	..	..	..	..	..	..	..	..
Azerbaijan	..	..	..	..	..	..	..	..
Belarus	..	..	..	..	..	..	..	..
Belgium	109 388	109 970	110 141	105 360	108 190	107 070	..	..
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	..	..	..	..	..	..	..	..
Canada	..	..	..	..	..	..	..	..
China	1 502 081	1 676 025	1 846 755	1 125 090	1 099 680	1 074 270	1 022 870	..
Croatia	..	..	..	..	..	..	..	..
Czech Republic	63 570 |	65 490 e	64 260 e	64 650 e	66 260 e	69 705 e	72 255 e	74 327 e
Denmark	59 759	59 759	60 190	60 854	60 195	60 862	60 071	..
Estonia	..	..	..	..	..	..	..	..
Finland	64 745	65 490	65 270	65 115	65 520	66 295	57 007 |	66 600 |
France	709 789	709 827	710 667	712 948	720 876	736 791	754 254	757 255
Georgia	..	..	..	..	..	..	..	..
Germany	884 800	894 400	896 300	903 100	916 400	927 000	946 500 p	..
Greece	..	..	..	..	..	..	..	..
Hungary	52 595	52 251	51 793	51 823	52 722 e	54 603 e	57 354	60 645 e
Iceland	4 958 e	4 777 e	4 832 e	4 971 e	5 226 e	5 578 e	6 468	..
India	..	..	..	..	..	..	..	..
Ireland	..	..	..	..	..	..	..	..
Italy	698 390	665 328	578 668	620 368	642 920	676 350	704 542 e	744 919 e
Japan	..	..	..	..	..	..	..	..
Korea	264 281	248 111	248 362	250 425	258 220	268 784	271 271	..
Latvia	..	..	..	..	..	..	..	..
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	32 569	29 908	34 191	33 325	24 366	24 865	25 854	31 361
Luxembourg	..	..	..	..	..	..	..	..
Malta	..	..	..	..	1 607 p	1 615 p	1 623 p	1 631 p
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	..	..	..	..	..	..	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	144 200	144 400	139 600	145 400	145 000	139 500	140 800	138 700
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	4 683 e	5 322 e	5 116 e	5 964 e	6 769 e	6 987 e	7 192 e	9 168
Norway	57 087	58 029	58 701	59 420	60 794	62 387	62 688	..
Poland	188 810 e	189 103 e	189 324 e	193 336 e	197 032 e	200 570 e	213 318 e	..
Portugal	..	..	..	..	..	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	295	283	338	337	263	351	450	499
Serbia, Republic of	..	..	..	..	..	..	..	..
Slovak Republic	26 879	26 887	26 935 e	27 155 e	27 251 e	27 531 e	27 836 e	28 125 e
Slovenia	25 636	..	..	..	..	..	..	..
Spain	341 629	334 021	321 045	316 539	308 704	317 553	329 880	..
Sweden	108 013	109 029	108 372	108 206	110 340	111 896	114 504	116 026 p
Switzerland	85 934	86 723	88 150	89 467	90 704	91 995	93 970	..
Turkey	..	..	..	..	..	..	..	..
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	644 687	644 149	647 256	641 810	654 335	655 127	665 500	670 415 p
United States	4 529 562	4 575 485	4 612 480	4 638 407	4 633 149	4 802 569	4 900 782	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Passenger transport by bus and coach

Million passenger-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	2 370 e	1 254 e	983 e	1 063 e	..	..	..	..
Armenia	..	..	..	..	..	..	..	..
Australia	19 501	19 918	20 422	20 745	21 078	21 204	..	..
Austria	..	..	..	..	..	..	..	..
Azerbaijan	16 633	18 264	20 034	21 880	22 992	23 825	24 429	24 886
Belarus	..	..	..	..	..	..	..	..
Belgium	17 385	17 670	17 905	16 170	15 790	15 170	..	..
Bosnia-Herzegovina	..	1 454	1 926	1 764	..	..	..	..
Bulgaria	9 924	9 766	9 233	8 916	10 145	10 231	9 757	9 179
Canada	..	..	..	..	..	..	..	..
China	..	..	..	..	..	..	..	..
Croatia	3 284	3 145	3 249	3 507	3 648	3 377	3 802	4 150
Czech Republic	10 816	9 267	9 015	9 026	10 010	9 996	10 257	11 178
Denmark	6 853	6 853	6 849	6 697	6 831	6 682	6 473	..
Estonia	2 266	2 260	2 490	2 619	2 569	3 315	2 995	2 929
Finland	7 540	7 540	7 540	7 540	7 540	7 540	8 255 |	8 200 |
France	54 375	54 932	55 543	56 130	57 565	58 540	58 913	58 134
Georgia	..	..	..	..	..	..	..	..
Germany	78 092	77 957	76 019	77 146	78 790	81 771	81 129 p	..
Greece	..	..	..	..	..	..	..	..
Hungary	16 250	16 259	16 868	16 965	17 441	17 618	17 623	18 100
Iceland	638 e	615 e	622 e	640 e	673 e	718 e	833	..
India	..	..	..	..	..	..	..	..
Ireland	..	..	..	..	..	..	..	..
Italy	102 219	102 444	101 512	101 770	102 806	102 640	103 099	103 174 e
Japan	77 750 |	73 988	75 668	74 571	72 579	71 443	70 119	69 815
Korea	114 582	115 207	106 838	109 503	110 296	109 260	102 648	..
Latvia	2 311	2 412	2 358	2 325	2 345	2 232	2 187	2 166
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	2 348	2 400	2 387	2 521	2 672	2 457	2 361	2 474
Luxembourg	..	..	..	..	..	..	..	..
Malta	..	..	..	..	332 p	339 p	345 p	351 p
Mexico	452 033 |	465 600	480 690	484 776	494 128	508 498	518 368	528 694
Moldova, Republic of	2 417	2 733	2 835	3 004	2 720	2 834	3 006	3 123
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	1 984	2 208	1 994	1 980	2 474	2 276	2 069	2 331
Norway	5 631 |	5 672	5 791	5 844	5 966	6 351	6 693	..
Poland	41 651 e	40 126 e	39 419 e	37 781 e	39 158 e	37 580 e	36 774 e	36 065 e
Portugal	..	5 850 |	5 850	6 023	5 657	5 857 |	6 756	..
Romania	11 955	11 773	12 584	12 923	14 061	..	..	..
Russian Federation	140 333	138 284	132 968	126 042	127 090	126 271	123 977	122 920
Serbia, Republic of	4 653	4 652	4 640	4 612	4 223	4 601	4 282	4 255
Slovak Republic	5 142	5 338	5 300	5 166	5 281	5 268	5 829	5 925
Slovenia	3 183	..	..	..	..	..	..	..
Spain	50 902	55 742	54 531	53 836	39 469	46 389	47 763	..
Sweden	9 922	10 262	10 101	10 312	10 288	10 436	10 501	10 639 p
Switzerland	6 486	6 677	6 837	6 895	7 016	7 163	7 306	..
Turkey	..	..	..	..	..	..	..	..
Ukraine	51 463	50 881	49 704	..	..	..	..	..
United Kingdom	44 723	42 607	42 226	40 382	39 618	39 367	34 364	37 979 p
United States	469 790	471 080	504 300	517 466	545 852	553 732	557 815	..

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Total passenger transport by road

Million passenger-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	7 905 e	7 980 e	7 637 e	8 650 e	..	..	..	..
Armenia	2 344	2 380	2 450	2 457	2 537	2 396	2 437	2 403
Australia	282 018	285 099	288 031	290 362	292 670	296 202	..	..
Austria	..	..	..	..	..	..	..	..
Azerbaijan	16 633	18 264	20 034	21 880	22 992	23 825	24 429	24 886
Belarus	..	..	..	..	..	..	..	..
Belgium	126 773	127 640	128 046	121 530	123 980	122 240	..	..
Bosnia-Herzegovina	..	1 454	1 926	1 764	..	..	..	..
Bulgaria	9 924	9 766	9 233	8 916	10 145	10 231	9 757	9 179
Canada	..	..	..	..	..	..	..	..
China	1 502 081	1 676 025	1 846 755	1 125 090	1 099 680	1 074 270	1 022 870	..
Croatia	3 284	3 145	3 249	3 507	3 648	3 377	3 802	4 150
Czech Republic	74 386 |	74 757	73 275	73 676	76 270	79 701	82 512	85 505
Denmark	66 612	66 612	67 039	67 551	67 027	67 544	66 544	..
Estonia	2 266	2 260	2 490	2 619	2 569	3 315	2 995	2 929
Finland	72 285	73 030	72 810	72 655	73 060	73 835	65 262 |	74 800 |
France	764 164	764 759	766 210	769 078	778 441	795 331	813 167	815 389
Georgia	5 885	6 049	6 219	6 393	6 572	6 756	6 945	7 140
Germany	962 892	972 357	972 319	980 246	995 190	1 008 771	1 027 629 p	..
Greece	..	..	..	..	..	..	..	..
Hungary	68 845	68 510	68 661	68 788	70 163 e	72 221 e	74 977 e	78 745 e
Iceland	5 596 e	5 392 e	5 454 e	5 611 e	5 899 e	6 296 e	7 301	..
India	8 409 000	9 478 000	10 393 000	11 756 000	13 403 000	15 415 000	17 496 000 e	19 718 000 e
Ireland	..	..	..	..	..	..	..	..
Italy	800 609	767 772	680 180	722 138	745 726	778 990	807 641	848 093
Japan	..	..	..	..	..	..	..	..
Korea	378 863	363 318	355 200	359 928	368 516	378 044	373 919	..
Latvia	2 311	2 412	2 358	2 325	2 345	2 232	2 187	2 166
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	34 917	32 308	36 578	35 846	27 038	27 322	28 215	33 835
Luxembourg	..	..	..	..	..	..	..	..
Malta	..	..	..	..	1 940 p	1 954 p	1 968 p	1 982 p
Mexico	452 033	465 600	480 690	484 776	494 128	508 498	518 368	528 694
Moldova, Republic of	2 417	2 733	2 835	3 004	2 720	2 834	3 006	3 123
Montenegro, Republic of	81	80	111	109	108	110	114	114
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	6 667 e	7 530 e	7 110 e	7 944 e	9 243 e	9 263 e	9 261 e	11 499
Norway	62 718 |	63 701	64 492	65 264	66 760	68 738	69 381	..
Poland	230 461 e	229 229 e	228 743 e	231 117 e	236 190 e	238 150 e	250 092 e	..
Portugal	..	..	..	..	..	..	..	..
Romania	11 955	11 773	12 584	12 923	14 061	..	..	..
Russian Federation	140 628	138 567	133 306	126 379	127 353	126 622	124 427	123 419
Serbia, Republic of	..	..	..	..	..	..	..	..
Slovak Republic	32 021	32 225	32 235	32 321	32 532	32 799	33 665	34 050
Slovenia	28 819	..	..	..	..	..	..	..
Spain	392 531	389 763	375 576	370 375	348 173	363 942	377 643	..
Sweden	117 935	119 291	118 473	118 518	120 628	122 357	125 162	126 665 p
Switzerland	92 419	93 400	94 988	96 363	97 720	99 158	101 276	..
Turkey	226 913	242 265	258 874	268 178	276 073	290 734	300 852	314 734
Ukraine	51 463	50 881	49 704	..	..	..	..	..
United Kingdom	689 410	686 756	689 483	682 191	693 953	694 493	699 865	708 393 p
United States	4 999 352	5 046 565	5 116 780	5 155 873	5 179 001	5 356 301	5 458 597	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Total inland passenger transport

Million passenger-kilometres

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	7 924	7 998	7 653	8 662	..	..	..	..
Armenia	2 394 e	2 429 e	2 503 e	2 512 e	2 589 e	2 440	2 598	2 666
Australia	296 768	300 073	303 287	305 584	307 908	311 876	..	..
Austria	..	..	..	..	..	..	..	..
Azerbaijan	17 550	18 924	20 625	22 489	23 604	24 320	24 877	25 353
Belarus	..	..	..	..	..	..	..	..
Belgium	137 176	138 643	..	132 125	134 954 e	132 573 e	..	..
Bosnia-Herzegovina	..	1 554	1 980	1 804	..	..	..	..
Bulgaria	12 024	11 834	11 109	10 742	11 847	11 783	11 215	10 617
Canada	..	..	..	..	..	..	..	..
China	2 378 299	2 637 254	2 827 988	2 184 650	2 223 870	2 270 330	2 280 800	..
Croatia	5 026	4 631	4 353	4 455	4 575	4 328	4 638	4 895
Czech Republic	80 977 |	81 471	80 540	81 277	84 067	87 999	91 355	95 002
Denmark	73 189	73 502	74 059	74 627	73 835	74 352	73 197	..
Estonia	2 514	2 501	2 726	2 844	2 851	3 604	3 311	3 296
Finland	76 244	76 912	76 845	76 708	76 934	77 948	69 130 |	79 071 |
France	866 331	870 355	872 166	874 293	883 030	900 180	917 365	925 853
Georgia	6 539	6 690	6 844	6 978	7 122	7 221	7 490	7 736
Germany	1 046 778	1 057 771	1 061 115	1 069 861	1 086 166	1 100 374	1 123 094 p	..
Greece	..	..	..	..	..	..	..	..
Hungary	76 537	76 316	76 467	76 631	77 901 e	79 830 e	82 630 e	86 476 e
Iceland	5 596 e	5 392 e	5 454 e	5 611 e	5 899 e	6 296 e	7 301	..
India	9 387 508	10 524 522	11 491 103	12 896 412	14 550 190	16 558 039	18 645 835 e	20 879 333 e
Ireland	..	..	..	..	..	..	..	..
Italy	847 781	814 617	726 939	770 877	795 683	831 197	859 819	..
Japan	..	..	..	..	..	..	..	..
Korea	437 244	426 362	425 279	426 281	436 376	446 415	451 756	..
Latvia	3 060	3 153	3 083	3 054	2 994	2 823	2 771	2 762
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	35 290	32 697	36 981	36 237	27 411	27 683	28 611	34 259
Luxembourg	..	..	..	..	..	..	..	..
Malta	..	..	..	..	1 940 p	1 954 p	1 968 p	1 982 p
Mexico	452 877	466 491	481 660	485 812	495 278	509 909	519 849	530 244
Moldova, Republic of	2 816	3 096	3 182	3 334	2 977	3 015	3 128	3 222
Montenegro, Republic of	172	145	173	182	184	191	198	174
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	6 822 e	7 675 e	7 209 e	8 024 e	9 323 e	9 441 e	9 344 e	11 558
Norway	66 401 |	67 345	68 275	69 207	70 908	73 056	73 908	..
Poland	248 382 e	247 406 e	246 569 e	247 914 e	252 205 e	255 517 e	269 267	..
Portugal	..	..	..	..	..	..	..	..
Romania	17 393	16 846	17 155	17 334	19 037	22 620	23 732	23 840
Russian Federation	279 513	278 309	277 918	264 896	257 380	247 266	249 047	246 515
Serbia, Republic of	..	..	..	..	..	..	..	..
Slovak Republic	34 330	34 656	34 694	34 806	35 115	36 210	37 260	37 923
Slovenia	29 632	..	..	..	..	..	..	..
Spain	414 987	412 558	398 052	394 163	373 245	390 097	404 313	..
Sweden	129 090	130 669	130 265	130 360	132 749	135 073	137 929	139 996 p
Switzerland	111 596	112 871	114 250	115 810	117 730	119 547	122 088	..
Turkey	232 404	248 147	263 472	271 955	280 466	295 562	305 177	..
Ukraine	101 711	101 474	99 033	..	..	..	..	..
United Kingdom	754 067	754 751	759 257	754 300	769 352	772 106	779 532	788 631 p
United States	5 009 684	5 057 135	5 127 729	5 166 832	5 189 743	5 366 820	5 469 091	..

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Road traffic injury accidents

Number of accidents

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	1 564	1 876	1 870	2 075	1 914	1 992	..	..
Armenia	1 974 e	2 319 e	2 602 e	2 824 e	3 156	3 399	3 203	3 535
Australia	..	..	..	..	..	..	..	..
Austria	35 348	35 129	40 831 |	38 502	37 957	37 960	38 466	37 402
Azerbaijan	2 721	2 890	2 892	2 846	2 635	2 220	2 006	1 833
Belarus	..	..	..	..	..	..	..	..
Belgium	45 745	47 761	44 259	41 347	41 474	40 300	40 123	38 020
Bosnia-Herzegovina	..	37 928	34 884	35 725	..	..	..	..
Bulgaria	6 609	6 639	6 717	7 015	7 018	7 225	7 404	6 888
Canada	125 636	124 199	124 683	122 143	116 278	118 060	117 673 p	..
China	219 521	210 812	204 196	198 394	196 812	187 781	212 846	..
Croatia	13 272	13 228	11 773	11 225	10 607	11 038	10 779	10 939
Czech Republic	19 676	20 487	20 504	20 342	21 054	21 561	21 386	21 263
Denmark	3 498	3 525	3 124	2 984	2 880	2 853	2 882	2 789
Estonia	1 347	1 492	1 383	1 364	1 413	1 376	1 468	1 406
Finland	6 072	6 408	5 725	5 334	5 324	5 185	4 730	4 752 p
France	67 288	65 024	60 437	56 812	58 191	56 603	57 522	58 613
Georgia	5 099	4 486	5 359	5 510	5 992	6 432	6 939	6 079
Germany	288 297	306 266	299 637	291 105	302 435	305 659	308 145	302 656
Greece	15 032	13 849	12 398	12 109	11 690	11 440	11 318	10 647 p
Hungary	16 308	15 827	15 174	15 691	15 847	16 331	16 627	16 489
Iceland	883	849	742	822	808	912	986	939
India	499 628	497 686	490 383	486 476	489 400	501 423	480 652	464 910
Ireland	5 780	5 230	5 610	4 976	5 797 p	5 831 p	5 573	5 927
Italy	212 997	205 638	188 228	181 660	177 031	174 539	175 791	174 933
Japan	725 924	692 084	665 157	629 033	573 842	536 899	499 201	472 165
Korea	226 878	221 711	223 656	215 354	223 552	232 035	220 917	216 335
Latvia	3 193	3 386	3 358	3 489	3 728	3 692	3 792	3 874
Liechtenstein	366	327	403	468	465	445	434	436
Lithuania	3 530	3 266	3 391	3 391	3 225	3 033	3 201	3 059
Luxembourg	876	962	1 019	949	908	983	941	955
Malta	13 727	14 624	14 546	14 070	14 473	15 504	15 017	15 003
Mexico	14 581	11 473	12 888	21 636	17 909	16 994	12 553	11 873
Moldova, Republic of	2 921	2 825	2 713	2 603	2 536	2 559	2 472	2 479
Montenegro, Republic of	1 520	1 451	1 217 |	1 266	1 334	1 554	1 698	1 831
Netherlands	3 853 e	..	..	..	..	..	..	..
New Zealand	10 886	9 804	9 604	9 347	8 880	9 737	9 968	11 126
North Macedonia	4 223	4 462	4 108	4 230	3 852	3 854	3 902	4 019
Norway	6 434	6 079	6 154	5 241	4 972	4 563	4 374	4 086
Poland	38 832	40 065	37 062	35 847	34 970	32 967	33 664	32 760
Portugal	35 426	32 541	29 867	30 339	30 604	31 953	32 299	34 416
Romania	25 996	26 648	26 928	24 827	25 355	28 944	30 751	31 106
Russian Federation	199 431	199 868	203 597	204 068	199 723	184 000	173 694	169 432
Serbia, Republic of	14 179	14 119	13 333	13 522	13 043	13 638	14 382	14 691
Slovak Republic	6 570	5 775	5 370	5 113	5 391	5 502	5 602	5 638
Slovenia	7 560	7 218	6 864	6 542	6 264	6 585	6 495	6 185
Spain	85 503	83 027	83 115	89 519	91 570	97 756	102 362	..
Sweden	16 500 |	16 119	16 458	14 815	12 926	14 672	14 051	14 849
Switzerland	19 609	18 990	18 148	17 473	17 803	17 736	17 577	17 799
Turkey	116 804	131 845	153 552	161 306	168 512	183 011	185 128	182 669
Ukraine	31 914	31 281	30 699	..	..	..	..	..
United Kingdom	160 080	157 068	151 346	144 426	152 407	146 203	142 846	136 063
United States	1 572 000 e	1 530 000 e	1 634 000 e	1 621 000 e	1 648 000 e	1 747 000 e	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Road traffic casualties (injuries plus fatalities)

Number

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	2 069	2 472	2 569	2 798	2 617	2 692	..	..
Armenia	2 964 e	3 681 e	4 050 e	4 310 e	4 776	5 084	4 718	5 458
Australia	34 128	35 359	35 391	24 246	..	..	..	..
Austria	46 410	45 548	51 426 |	48 499	48 100	47 845	48 825	47 258
Azerbaijan	3 796	4 047	4 165	4 112	3 800	3 159	2 762	2 469
Belarus	..	..	..	..	..	..	..	..
Belgium	59 872	62 195	57 146	53 876	53 982	52 593	51 928	49 066
Bosnia-Herzegovina	..	10 395	9 478	10 052	..	..	..	..
Bulgaria	8 854	8 958	8 794	9 376	9 299	9 679	10 082	9 362
Canada	174 319	169 764	168 803	166 476	158 214	160 566	162 213 p	..
China	319 299	299 808	284 324	272 263	270 405	257 902	289 523	..
Croatia	18 759	18 483	16 403	15 642	14 530	15 372	14 903	14 939
Czech Republic	25 186	26 322	26 257	25 942	27 046	27 704	27 692	27 656
Denmark	4 408	4 259	3 778	3 585	3 375	3 334	3 439	3 318
Estonia	1 799	1 980	1 794	1 761	1 790	1 792	1 917	1 773
Finland	7 945	8 223	7 343	6 939	6 934	6 678	6 144	5 806 p
France	88 453	85 214	79 504	73 875	76 432	74 263	76 122	77 093
Georgia	8 245	7 164	8 339	8 559	9 047	9 789	10 532	8 978
Germany	374 818	396 374	387 978	377 481	392 912	396 891	399 872	393 492
Greece	20 366	18 400	16 628	16 054	15 359	14 889	14 649	13 657 p
Hungary	21 657	20 810	19 584	20 681	20 750	21 543	22 543	22 076
Iceland	1 261	1 217	1 044	1 232	1 172	1 324	1 429	1 387
India	662 025	653 897	647 925	632 465	633 145	646 412	645 409	618 888
Ireland	8 482	7 421	8 105	7 068	8 272 p	8 002 p	8 106	..
Italy	308 834	295 879	270 617	261 494	254 528	250 348	252 458	250 128
Japan	901 245	859 304	829 830	785 880	715 487	670 140	622 757	584 544
Korea	357 963	346 620	349 957	333 803	342 259	355 021	336 012	327 014
Latvia	4 241	4 403	4 356	4 517	4 815	4 754	4 806	4 954
Liechtenstein	114	107	109	113	101	113	105	89
Lithuania	4 529	4 215	4 253	4 263	4 014	3 836	3 941	3 758
Luxembourg	1 217	1 341	1 412	1 297	1 261	1 384	1 235	1 297
Malta	1 079	1 577	1 599	1 582	1 796	1 711	1 852	1 873
Mexico	33 649	30 451	29 275	24 542	21 182	18 960	14 534	11 824
Moldova, Republic of	4 197	3 978	3 952	3 522	3 404	3 363	3 235	3 229
Montenegro, Republic of	2 194	2 133	1 768	1 886	1 900	2 224	2 423	2 711
Netherlands	4 291 e	..	..	..	..	..	..	..
New Zealand	14 406	12 858	12 430	12 034	11 512	12 589	12 784	14 270
North Macedonia	6 357	7 025	6 281	6 682	6 186	6 061	6 136	6 379
Norway	9 338	8 531	8 340	7 029	6 438	5 804	5 674	5 368
Poland	52 859	53 690	49 369	47 416	45 747	42 716	43 792	42 297
Portugal	47 302	42 851	38 823	39 390	39 653	41 549	41 668	44 485
Romania	34 791	35 509	36 251	33 325	34 152	38 790	41 475	42 162
Russian Federation	277 202	279 801	286 609	285 462	278 751	254 311	241 448	234 462
Serbia, Republic of	19 982	20 040	19 090	19 118	18 529	19 909	21 212	21 717
Slovak Republic	8 503	7 382	6 790	6 562	6 912	7 059	7 216	7 160
Slovenia	10 454	9 814	9 278	8 867	8 328	8 830	8 586	8 005
Spain	122 823	117 687	117 793	126 400	128 320	136 144	142 200	..
Sweden	23 571 |	22 679	23 110	20 522	17 795	19 902	18 933	19 915
Switzerland	24 564	23 562	22 557	21 648	21 764	21 791	21 608	21 643
Turkey	215 541	241 909	271 829	278 514	288 583	311 951	311 112	307 810
Ukraine	43 850	43 086	42 650	..	..	..	..	..
United Kingdom	217 605	212 710	204 733	192 693	203 865	195 926	190 975	180 177
United States	2 272 000 e	2 249 000 e	2 396 000 e	2 346 000 e	2 371 000 e	2 478 000 e	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Road traffic injuries

Number

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	1 716	2 150	2 235	2 503	2 353	2 422	..	..
Armenia	2 670 e	3 354 e	3 739 e	3 994 e	4 479	4 738	4 451	5 179
Australia	32 775	34 082	34 091	23 059	..	..	..	..
Austria	45 858	45 025	50 895 |	48 044	47 670	47 366	48 393	47 258
Azerbaijan	2 871	3 031	2 997	2 948	2 676	2 265	2 003	1 719
Belarus	..	..	..	..	..	..	..	..
Belgium	59 022	61 311	56 319	53 112	53 237	51 831	51 258	48 451
Bosnia-Herzegovina	..	10 039	9 175	9 718	..	..	..	..
Bulgaria	8 078	8 301	8 193	8 775	8 639	8 971	9 374	8 680
Canada	172 081	167 741	166 728	164 525	156 366	158 706	160 315 p	..
China	254 074	237 421	224 327	213 724	211 882	199 880	226 430	..
Croatia	18 333	18 065	16 010	15 274	14 222	15 024	14 596	14 608
Czech Republic	24 384	25 549	25 515	25 288	26 358	26 966	27 081	27 079
Denmark	4 153	4 039	3 611	3 394	3 193	3 156	3 228	3 143
Estonia	1 720	1 879	1 707	1 680	1 712	1 725	1 846	1 725
Finland	7 673	7 931	7 088	6 681	6 705	6 408	5 888	5 576 p
France	84 461	81 251	75 851	70 607	73 048	70 802	72 645	73 645
Georgia	7 560	6 638	7 734	8 045	8 536	9 187	9 951	8 461
Germany	371 170	392 365	384 378	374 142	389 535	393 432	396 666	390 312
Greece	19 108	17 259	15 640	15 175	14 564	14 096	13 825	12 925 p
Hungary	20 917	20 172	18 979	20 090	20 124	20 899	21 936	21 451
Iceland	1 253	1 205	1 035	1 217	1 168	1 308	1 411	1 371
India	527 512	511 412	509 667	494 893	493 474	500 279	494 624	470 975
Ireland	8 270	7 235	7 942	6 880	8 079 p	7 840 p	7 920	..
Italy	304 720	292 019	266 864	258 093	251 147	246 920	249 175	246 750
Japan	895 417	853 769	824 569	780 715	710 649	665 255	618 059	580 113
Korea	352 458	341 391	344 565	328 711	337 497	350 400	331 720	322 829
Latvia	4 023	4 224	4 179	4 338	4 603	4 566	4 648	4 818
Liechtenstein	114	105	108	111	98	111	105	87
Lithuania	4 230	3 919	3 951	4 007	3 747	3 594	3 749	3 567
Luxembourg	1 185	1 308	1 378	1 252	1 226	1 348	1 203	1 272
Malta	1 064	1 560	1 590	1 564	1 786	1 700	1 829	1 854
Mexico	28 617	26 045	24 736	20 693	17 408	15 470	11 163	8 905
Moldova, Republic of	3 745	3 535	3 510	3 221	3 080	3 063	2 924	2 928
Montenegro, Republic of	2 099	2 075	1 722	1 812	1 835	2 173	2 358	2 648
Netherlands	3 651 e	..	..	..	..	..	..	..
New Zealand	14 031	12 574	12 122	11 781	11 219	12 270	12 456	13 892
North Macedonia	6 195	6 853	6 149	6 484	6 056	5 913	5 971	6 224
Norway	9 130	8 363	8 195	6 842	6 291	5 687	5 539	5 262
Poland	48 952	49 501	45 792	44 059	42 545	39 778	40 766	39 466
Portugal	46 365	41 960	38 105	38 753	39 015	40 956	41 105	43 893
Romania	32 414	33 491	34 209	31 464	32 334	36 897	39 562	40 211
Russian Federation	250 635	251 848	258 618	258 437	251 793	231 197	221 140	215 374
Serbia, Republic of	19 326	19 312	18 406	18 472	17 993	19 308	20 606	21 139
Slovak Republic	8 150	7 057	6 438	6 311	6 617	6 749	6 941	6 884
Slovenia	10 316	9 673	9 148	8 742	8 220	8 710	8 456	7 901
Spain	120 345	115 627	115 890	124 720	126 632	134 455	140 390	..
Sweden	23 305 |	22 360	22 825	20 262	17 525	19 643	18 663	19 662
Switzerland	24 237	23 242	22 218	21 379	21 521	21 538	21 392	21 413
Turkey	211 496	238 074	268 079	274 829	285 059	304 421	303 812	300 383
Ukraine	38 975	38 178	37 519	..	..	..	..	..
United Kingdom	215 700	210 750	202 931	190 923	202 011	194 122	189 115	178 321
United States	2 239 000 e	2 217 000 e	2 362 000 e	2 313 000 e	2 338 000 e	2 443 000 e	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Road traffic fatalities

Number

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	353	322	334	295	264	270	..	..
Armenia	294 e	327 e	311 e	316 e	297	346	267	279
Australia	1 353	1 277	1 300	1 187	1 150	1 205	1 295	1 226
Austria	552	523	531 |	455	430	479	432	414
Azerbaijan	925	1 016	1 168	1 164	1 124	894	759	750
Belarus	..	..	..	..	..	..	..	..
Belgium	850	884	827	764	745	762	670	615
Bosnia-Herzegovina	..	356	303	334	..	..	..	..
Bulgaria	776	657	601	601	660	708	708	682
Canada	2 238	2 023	2 075	1 951	1 848	1 860	1 898 p	..
China	65 225	62 387	59 997	58 539	58 523	58 022	63 093	..
Croatia	426	418	393	368	308	348	307	331
Czech Republic	802	773	742	654	688	738	611	577
Denmark	255	220	167	191	182	178	211	175
Estonia	79	101	87	81	78	67	71	48
Finland	272	292	255	258	229	270	256	230 p
France	3 992	3 963	3 653	3 268	3 384	3 461	3 477	3 448
Georgia	685	526	605	514	511	602	581	517
Germany	3 648	4 009	3 600	3 339	3 377	3 459	3 206	3 180
Greece	1 258	1 141	988	879	795	793	824	732 p
Hungary	740	638	605	591	626	644	607	625
Iceland	8	12	9	15	4	16	18	16
India	134 513	142 485	138 258	137 572	139 671	146 133	150 785	147 913
Ireland	212	186	163	188	193 p	162 p	186 p	157 p
Italy	4 114	3 860	3 753	3 401	3 381	3 428	3 283	3 378
Japan	5 828	5 535	5 261	5 165	4 838	4 885	4 698	4 431
Korea	5 505	5 229	5 392	5 092	4 762	4 621	4 292	4 185
Latvia	218	179	177	179	212	188	158	136
Liechtenstein	0	2	1	2	3	2	0	2
Lithuania	299	296	302	256	267	242	192	191
Luxembourg	32	33	34	45	35	36	32	25
Malta	15	17	9	18	10	11	23	19
Mexico	5 032	4 406	4 539	3 849	3 774	3 490	3 371	2 919
Moldova, Republic of	452	443	442	301	324	300	311	301
Montenegro, Republic of	95	58	46	74	65	51	65	63
Netherlands	640	661	650	570	570	621	629	613
New Zealand	375	284	308	253	293	319	328	378
North Macedonia	162	172	132	198	130	148	165	155
Norway	208	168	145	187	147	117	135	106
Poland	3 907	4 189	3 577	3 357	3 202	2 938	3 026	2 831
Portugal	937	891	718	637	638	593	563	592
Romania	2 377	2 018	2 042	1 861	1 818	1 893	1 913	1 951
Russian Federation	26 567	27 953	27 991	27 025	26 958	23 114	20 308	19 088
Serbia, Republic of	656	728	684	646	536	601	606	578
Slovak Republic	353	325	352	251	295	310	275	276
Slovenia	138	141	130	125	108	120	130	104
Spain	2 478	2 060	1 903	1 680	1 688	1 689	1 810	..
Sweden	266 |	319	285	260	270	259	270	253
Switzerland	327	320	339	269	243	253	216	230
Turkey	4 045	3 835	3 750	3 685	3 524	7 530 |	7 300	7 427
Ukraine	4 875	4 908	5 131	4 824 p	..	..	..	..
United Kingdom	1 905	1 960	1 802	1 770	1 854	1 804	1 860	1 856
United States	32 999	32 479	33 561	32 719	32 675	35 092	37 461	37 150 e

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Road traffic fatalities, per million inhabitants

Number

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	121.2	110.8	115.2	101.9	91.4	93.7	..	..
Armenia	102.2 e	113.7 e	107.9 e	109.2 e	102.2	118.6	91.3	95.2
Australia	61.4	57.2	57.2	51.3	48.9	50.5	53.5	49.8
Austria	66.0	62.3	63.0 |	53.7	50.3	55.4	49.4	47.2
Azerbaijan	102.2	110.8	125.7	123.6	117.9	92.7	77.8	76.0
Belarus	..	..	..	..	..	..	..	..
Belgium	78.0	80.0	74.3	68.3	66.5	67.6	59.1	54.1
Bosnia-Herzegovina	..	96.5	83.1	92.7	..	..	..	..
Bulgaria	104.9	89.4	82.3	82.7	91.4	98.6	99.3	96.4
Canada	65.8	58.9	59.7	55.5	52.0	51.9	52.3	..
China	..	..	..	..	..	..	..	..
Croatia	96.4	97.7	92.1	86.5	72.7	82.8	73.5	80.2
Czech Republic	76.6	73.7	70.6	62.2	65.4	70.0	57.9	54.5
Denmark	46.0	39.5	29.9	34.0	32.3	31.3	36.8	30.4
Estonia	59.3	76.1	65.8	61.5	59.3	50.9	54.0	36.5
Finland	50.7	54.2	47.1	47.4	41.9	49.3	46.6	41.7
France	61.4	60.7	55.6	49.5	51.0	52.0	52.0	51.4
Georgia	174.5	135.7	158.2	136.1	137.1	162.0	156.2	139.1
Germany	44.6	49.9	44.8	41.4	41.7	42.3	38.9	38.5
Greece	113.1	102.8	89.5	80.2	73.0	73.3	76.5	68.0
Hungary	74.0	64.0	61.0	59.7	63.5	65.4	61.8	63.9
Iceland	25.2	37.6	28.1	46.3	12.2	48.4	53.7	46.9
India	109.3	114.2	109.5	107.6	108.0	111.6	113.9	110.5
Ireland	46.5	40.6	35.4	40.7	41.4	34.5	39.1	32.6
Italy	69.4	65.0	63.0	56.5	55.6	56.5	54.2	55.8
Japan	45.5	43.3	41.2	40.5	38.0	38.4	37.0	34.9
Korea	111.1	104.7	107.4	101.0	93.8	90.6	83.8	81.3
Latvia	103.9	86.9	87.0	88.9	106.3	95.1	80.6	70.1
Liechtenstein	0.0	55.2	27.4	54.3	80.8	53.5	0.0	52.7
Lithuania	96.5	97.8	101.1	86.6	91.1	83.3	66.9	67.5
Luxembourg	63.1	63.7	64.0	82.8	62.9	63.2	55.5	42.3
Malta	36.2	40.8	21.5	42.3	23.0	24.7	50.5	40.8
Mexico	42.9	37.0	37.6	31.4	30.4	27.7	26.4	22.6
Moldova, Republic of	126.9	124.4	124.2	84.6	91.1	84.4	87.6	84.8
Montenegro, Republic of	153.4	93.5	74.1	119.1	104.5	82.0	104.5	101.2
Netherlands	38.5	39.6	38.8	33.9	33.8	36.7	36.9	35.8
New Zealand	86.2	64.8	69.9	57.0	65.0	69.4	69.9	78.9
North Macedonia	78.2	83.0	63.6	95.4	62.6	71.2	79.3	74.4
Norway	42.5	33.9	28.9	36.8	28.6	22.6	25.8	20.1
Poland	102.7	110.1	94.0	88.3	84.2	77.3	79.7	74.5
Portugal	88.6	84.4	68.3	60.9	61.3	57.3	54.5	57.4
Romania	117.4	100.2	101.8	93.1	91.3	95.5	97.1	99.6
Russian Federation	186.0	195.5	195.5	188.3	187.4	160.4	140.7	132.1
Serbia, Republic of	90.0	100.6	95.0	90.2	75.2	84.7	85.9	82.3
Slovak Republic	65.5	60.2	65.1	46.4	54.4	57.2	50.7	50.7
Slovenia	67.4	68.7	63.2	60.7	52.4	58.2	63.0	50.3
Spain	53.2	44.1	40.7	36.0	36.3	36.4	39.0	..
Sweden	28.4 |	33.8	29.9	27.1	27.9	26.4	27.2	25.1
Switzerland	41.8	40.4	42.4	33.3	29.7	30.6	25.8	27.2
Turkey	55.9	52.2	50.3	48.6	45.8	96.2 |	91.8	92.0
Ukraine	106.3	107.4	112.5	106.1 p	..	..	..	..
United Kingdom	30.4	31.0	28.3	27.6	28.7	27.7	28.4	28.1
United States	106.7	104.2	106.9	103.5	102.6	109.3	115.8	114.1

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Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Road traffic fatalities, per million motor vehicles

Number

	2010	2011	2012	2013	2014	2015	2016	2017
Albania	..	..	..	..	..	..	..	..
Armenia	..	..	..	..	..	..	..	..
Australia	84.2	78.0	77.7	69.1	65.2	66.9	70.4 p	65.3
Austria	92.3	85.9	85.7 |	72.2	67.4	74.1	66.0	62.2
Azerbaijan	..	..	..	..	..	..	..	..
Belarus	..	..	..	..	..	..	..	..
Belgium	127.1	128.8	119.5	109.2	105.3	106.2	91.8	82.9
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	249.0	203.3	178.3	171.6	181.2	184.7	184.6	..
Canada	102.4	90.9	92.8	84.8	78.5	77.7	78.2	..
China	..	..	..	..	..	..	..	..
Croatia	243.4	238.8	237.0	221.4	181.9	201.7	171.3	..
Czech Republic	133.2	126.7	119.6	102.7	108.2	113.6	89.0	81.2
Denmark	88.2	75.9	57.0	64.6	61.0	58.8	68.3	55.3
Estonia	119.9	147.5	121.1	107.9	..	..	..	..
Finland	70.6	72.8	61.7	60.9	52.8 e	61.0	56.3	..
France	99.4	98.0	86.4 e	77.2 e	79.7 e	81.1 e	80.8 e	79.4
Georgia	..	..	..	..	..	..	..	..
Germany	69.8	75.7	66.9	61.3	61.4	62.0	56.6	55.3
Greece	133.1	120.1	104.1	93.0	84.1	83.3	86.8	75.8
Hungary	203.3	179.9	169.6	160.1 |	165.7	165.7	150.9	148.4
Iceland	30.8	46.0	33.8	55.6	14.6	56.1	59.4	..
India	..	..	..	..	..	..	..	..
Ireland	87.7	76.7	67.8	75.7	76.7 p	63.0 p	70.9 p	58.7
Italy	80.3	75.2	73.2	66.3	65.5	66.0	62.3	63.1
Japan	64.4	61.3	58.4	57.0	53.2	53.5	51.4	48.5
Korea	264.3	243.8	246.1	227.3	207.5	195.3	174.7	164.7
Latvia	296.1 |	251.2	244.9	240.8	276.4	237.2	204.0	..
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	139.4	136.2	135.0	112.5	179.3 |	156.2	119.0	121.0
Luxembourg	77.8	78.7	79.1	101.8	81.2 e	81.2	70.5	53.6
Malta	49.5	54.8	28.8	56.1	30.0	31.9	64.5	..
Mexico	159.1	132.4	130.2	104.8	99.3 p	87.3	79.4	64.2
Moldova, Republic of	..	..	..	..	..	..	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	68.5	69.9	67.9	59.3	59.3	64.3	64.3	..
New Zealand	116.1	87.8	94.8	76.6	86.2	90.8	89.7	98.8
North Macedonia	..	..	..	..	..	..	..	..
Norway	59.5	46.8	39.3	49.9	38.6	30.0	34.0	..
Poland	176.7	181.2	150.5	136.9	126.8	112.4	110.8	..
Portugal	161.7	..	124.3	111.3	111.5	102.9	97.0	..
Romania	462.7	389.1	380.2	330.7	308.5	305.3	290.6	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	362.5	380.3	343.4	315.3	257.1	279.3	270.8	237.6
Slovak Republic	174.2	152.9	159.2	110.1	125.0	125.8	107.2	..
Slovenia	103.6	105.4	96.2	92.3	78.7	86.0	91.3	70.6
Spain	74.3	61.5	57.0	50.9	51.1	50.6	53.1	..
Sweden	47.1 |	56.8	49.5	44.7	45.6	43.0	43.9	..
Switzerland	59.2	56.7	58.9	46.1	40.9	41.8	35.1	36.9
Turkey	309.4	273.5	251.2	232.7	211.3	423.6 |	388.1	..
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	54.2	55.6	50.6	49.0	50.5	48.0	48.5	..
United States	128.3	122.5	126.3	121.5	118.9	124.7	130.1	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Investment in rail transport infrastructure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	0.1	0.3	0.9	0.5	0.7	0.7	0.5	0.0
Armenia	53.2	42.7	26.4	23.9	11.7	12.0	12.4	5.6
Australia	2 285.0	3 611.6	5 164.9	6 602.3	4 975.6	4 320.3	2 799.6	2 627.6
Austria	2 062.0	1 936.0	2 143.0	1 688.0	1 648.0	1 567.0	1 549.0	1 523.0
Azerbaijan	2.7	2.8	2.7	3.0	3.8	3.8	1.8	1.1
Belarus	..	..	..	..	..	..	..	..
Belgium	1 404.3	1 376.5	1 295.1	1 333.4	1 200.8	1 108.0 |	1 006.0	959.1
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	49.6	129.9	90.0	114.0	123.7	167.2	301.2	301.2
Canada	493.3	697.4	869.4	1 044.5	1 011.4	962.6	1 063.1	768.5 p
China	70 183.4	85 005.4	65 833.8	75 538.5	81 347.4	94 554.3	111 893.1	..
Croatia	98.2	83.4	80.5	61.8	183.1	130.7	60.0	44.3
Czech Republic	740.6	563.2	446.8	381.5	334.7	454.2	1 164.9	681.5
Denmark	356.7	396.4	862.9	915.8	996.1	1 159.4	1 308.4	1 185.0
Estonia	37.0	35.0	94.0	47.7	26.5	15.5	13.1	15.4
Finland	361.0	388.0	355.0	450.0	605.0	643.0	567.0	537.0
France	3 386.0	3 277.0	4 589.0	5 381.0	7 808.0	6 823.0	6 224.0	5 244.0
Georgia	91.3	83.4	266.8	243.8	62.7	76.5	88.2	88.7
Germany	3 412.0	3 807.0	4 086.0	3 930.0	4 210.0	4 420.0	4 750.0	4 840.0
Greece	467.0	212.0	185.0	177.0	96.0	180.6 e	218.5 e	..
Hungary	317.6	272.0 |	348.8	472.4	623.2	626.7	701.3	323.2
Iceland	x	x	x	x	x	x	x	x
India	4 723.7	5 149.6	4 944.4	6 075.9	5 928.6	8 777.9	11 462.5	..
Ireland	..	..	..	..	..	..	..	..
Italy	5 687.0	4 773.0	4 466.0	4 238.0	4 103.0	4 742.0	2 861.0	..
Japan	9 601.9	11 305.9	10 208.8	11 803.1	9 192.0	8 644.3	8 880.2	9 174.7
Korea	4 629.2	5 258.7	4 937.8	5 964.5	5 838.4	6 175.6	8 589.3	..
Latvia	63.0	73.0	53.0	102.0	77.0	136.0	209.0	24.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	67.0	107.0	116.0	140.0	139.0	264.0	180.0	70.0
Luxembourg	172.3	156.5	150.4	124.9	145.9	191.5	277.7	..
Malta	x	x	x	x	x	x	x	x
Mexico	437.6	434.8	649.9	590.7	699.3	997.8	1 150.1	1 355.9
Moldova, Republic of	8.5	7.3	7.2	10.4	12.8	4.5	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	778.0	1 097.0	1 136.0	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	..	..	..	..	..	..	..	..
Norway	358.6	479.3	561.1	675.8	838.7	1 218.3	1 281.4	..
Poland	649.9	690.1	925.3	430.9	262.8	53.1	340.4	326.6
Portugal	360.0	403.0	333.0	86.0	71.0	120.0	177.0	79.0
Romania	177.4	168.9	161.4	117.8	208.9	277.7	321.9	262.1
Russian Federation	6 576.6	9 052.4	9 872.1	11 194.2	9 786.8	6 474.6	5 022.3	4 830.4
Serbia, Republic of	5.7	12.2	7.0	2.9	9.3	11.8	83.1	73.3 p
Slovak Republic	175.0 |	273.0	289.0	216.0	324.0	276.0	295.5	131.6
Slovenia	72.0	131.0	106.0	72.0	140.0	270.0	376.0	84.4
Spain	8 772.0	7 669.0	7 553.0	5 350.0	2 710.0	3 042.0	2 631.0	1 682.0 p
Sweden	1 318.6	1 432.2	1 400.5	1 329.9	1 104.1	1 187.4	1 387.7 |	1 177.5
Switzerland	2 888.3	3 032.1	3 410.0	3 463.9	3 665.6	3 550.1	4 193.5	4 056.1
Turkey	771.3	1 505.4	1 526.2	1 508.5	2 254.4	1 380.6	1 081.0	1 718.2
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	6 307.1	6 387.1	7 532.7	8 765.9	8 426.4	10 094.3	14 327.4 |	13 578.4
United States	7 140.6	7 364.3	8 335.8	10 478.4	9 856.2	11 347.8	15 687.6	..

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Investment in road transport infrastructure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	486.9	241.9	210.2	180.8	234.2	192.7	179.2	89.1
Armenia	84.2	36.5	30.5	26.5	23.2	66.8	77.7	90.4
Australia	9 195.9	11 200.6	13 802.0	15 900.9	12 734.4	10 438.6	10 475.3	11 874.7
Austria	665.0	390.0	303.0	327.0	363.0	453.0	455.0	444.0
Azerbaijan	1 272.0	1 545.5	1 561.8	1 484.2	1 913.6	1 411.3	873.2	498.1
Belarus	..	..	..	..	..	..	..	..
Belgium	175.0	348.0 |	248.0	553.0	587.0	417.0	778.0 p	810.0
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	101.2	281.2	344.1	387.6	359.4	252.6	252.6	252.6
Canada	10 890.1	15 378.7	15 066.2	14 756.4	13 086.1	5 108.7 |	5 636.8	5 767.1 p
China	111 241.4	142 354.1	154 221.3	215 276.5	249 280.0	300 735.3	414 199.5	..
Croatia	909.1	515.3	465.7	478.6	424.2	279.5	238.4	197.4
Czech Republic	1 985.4	1 719.5	1 293.2	876.3	647.5	604.0	885.4	849.2
Denmark	713.8	936.6	1 052.0	1 323.7	1 046.9	1 101.6	1 086.4	1 099.5
Estonia	119.0	137.0	158.0	213.8	224.1	170.5	206.2	173.9
Finland	922.0	890.0	973.0	1 128.0	1 148.0	1 238.0	1 243.0	1 269.0
France	14 277.8	14 497.1	12 604.3	13 173.7	12 866.2	10 807.2	10 011.2	9 242.4
Georgia	218.8	232.7	247.6	177.4	236.7	224.5	194.1	202.5
Germany	12 620.0	11 240.0	11 340.0	11 530.0	11 730.0	11 780.0	11 690.0	12 390.0
Greece	1 791.0	1 394.0	1 310.0	1 088.0	2 181.0	1 597.9 e	1 385.8 e	..
Hungary	1 565.2	840.2	298.0	152.7	400.6	1 238.4	1 247.7	802.7
Iceland	120.9	79.3	38.7 |	37.9	41.8	45.3	67.4	..
India	4 807.3	6 359.8	5 616.7	6 208.4	8 475.2	9 773.4	15 107.5	..
Ireland	1 769.0	1 414.0	1 017.0	886.0	594.0	638.0	612.0	..
Italy	5 641.0	3 389.0	4 129.0	3 107.0	2 841.0	3 860.0	5 151.0	..
Japan	37 207.0	35 766.3	35 812.5	37 300.8	33 129.2	29 831.9	28 143.4	..
Korea	12 188.7	10 791.4	9 243.6	10 780.7	11 337.2	10 904.6	13 174.2	..
Latvia	132.0	131.0	222.0	190.0	199.0	188.0	203.0	190.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	448.0	422.0	343.0	243.0	253.0	224.0	258.0	357.0
Luxembourg	148.5	182.6	222.0	213.4	220.1	203.9	221.0	..
Malta	3.7	12.6	17.3	26.7	11.1	38.5	..	..
Mexico	3 020.6	3 937.1	3 915.8	3 985.3	4 180.0	4 883.3	4 296.3	3 383.3
Moldova, Republic of	13.4	13.8	8.1	40.2	36.2	38.9	..	..
Montenegro, Republic of	23.0	18.0	15.0	18.0	20.0	9.0	12.0	..
Netherlands	2 363.0	2 300.0	2 287.0	..	..	..	..	..
New Zealand	578.7	731.7	842.0	668.2	766.0	952.3	1 143.5	..
North Macedonia	103.8	83.6	103.9	70.5	87.5	174.3	166.3	228.6
Norway	2 488.3	2 674.0	2 811.6	3 301.1	3 844.3	3 804.0	3 559.5	..
Poland	5 337.7	6 509.6	8 323.3	4 382.8	2 464.8	1 721.1	2 170.8	3 075.4
Portugal	951.0 |	1 511.0	..	274.0 p	211.0 p	..	..	..
Romania	3 105.2	2 851.1	3 283.6	3 092.8	2 728.7	2 492.6	2 870.3	2 366.8
Russian Federation	6 242.2	6 200.7	8 423.7	9 281.4	9 836.0	8 283.7	6 117.2	7 597.0
Serbia, Republic of	251.5	228.8	339.0	256.6	279.3	337.0	505.1	493.8 p
Slovak Republic	662.0	342.0	432.0	311.0	360.0	550.0	1 133.8	745.6
Slovenia	406.0	221.0	112.0	102.0	104.0	128.0	102.0	100.0
Spain	9 422.0	7 851.0	5 966.0	5 316.0	4 646.0	4 358.0	4 393.0	3 749.0 p
Sweden	1 573.7	1 666.1	1 911.7	2 212.1	2 013.1	1 864.8	1 861.5	2 086.3
Switzerland	2 996.9	3 418.5	3 822.5	3 880.4	3 731.4	3 647.3	..	..
Turkey	3 454.9	5 135.4	5 204.6	4 801.9	6 226.1	6 643.9	9 056.8	7 329.6
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	6 566.6	6 482.9	5 565.0	5 557.5	6 029.9	7 845.6	9 067.9	8 608.1
United States	59 355.5	63 536.3	60 429.7	64 483.5	62 415.3	64 494.3	81 470.8	82 233.9

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Investment in inland waterway transport infrastructure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0
Armenia	x	x	x	x	x	x	x	x
Australia	x	x	x	x	x	x	x	x
Austria	5.0	11.0	2.0	3.0	11.0	10.0	2.0	2.0
Azerbaijan	..	..	..	118.8	424.2	260.0	80.2	40.8
Belarus	..	..	..	..	..	..	..	..
Belgium	188.0	154.0 |	152.0	152.0	167.0	103.0	291.0	225.0
Bosnia-Herzegovina	x	x	x	x	x	x	x	x
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.5	1.3	0.5
Canada	..	..	..	..	..	..	..	..
China	..	..	..	..	..	..	..	..
Croatia	3.5	2.6	3.5	3.3	1.7	..	..	..
Czech Republic	58.9	57.8	22.3	17.2	7.2	9.6	15.1	9.8
Denmark	x	x	x	x	x	x	x	x
Estonia	x	x	x	x	x	x	x	x
Finland	2.0	2.0	1.0	2.0	3.0	2.0	2.0	2.0
France	693.4	758.6	949.0	938.6	744.5	702.4	700.6	972.0
Georgia	x	x	x	x	x	x	x	x
Germany	1 170.0	1 100.0	1 070.0	885.0	865.0	865.0	830.0	895.0
Greece	x	x	x	x	x	x	x	x
Hungary	3.1	0.7	0.2	0.0	0.1	0.0	0.0	10.3
Iceland	x	x	x	x	x	x	x	x
India	..	..	..	..	..	..	..	..
Ireland	x	x	x	x	x	x	x	x
Italy	27.0	42.0	36.0	52.0	136.0	358.0	509.0	..
Japan	x	x	x	x	x	x	x	x
Korea	x	x	x	x	x	x	x	x
Latvia	x	x	x	x	x	x	x	x
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	1.0	1.0	2.0	0.0	1.0	3.0	1.0	0.0
Luxembourg	0.3	1.0	1.3	0.7	0.1	0.3	0.0	..
Malta	x	x	x	x	x	x	x	x
Mexico	x	x	x	x	x	x	x	x
Moldova, Republic of	0.0	0.0	0.7	0.2	0.1	..	..	..
Montenegro, Republic of	x	x	x	x	x	x	x	x
Netherlands	361.0	252.0	263.0	..	..	..	..	..
New Zealand	x	x	x	x	x	x	x	x
North Macedonia	x	x	x	x	x	x	x	x
Norway	x	x	x	x	x	x	x	x
Poland	25.2	24.8	29.1	0.2	..	61.2	..	..
Portugal	5.0	1.0	1.0	3.0	0.0	..	..	..
Romania	536.1	423.5	519.0	279.5	268.1	314.1	505.9	236.9
Russian Federation	58.8	68.2	301.7	230.0	106.7	103.4	39.8	73.6
Serbia, Republic of	19.3	21.1	25.8	24.7	15.5	17.7	22.3	40.7 p
Slovak Republic	2.0	3.0	1.0	1.0	1.0	0.0	0.1	0.1
Slovenia	x	x	x	x	x	x	x	x
Spain	x	x	x	x	x	x	x	x
Sweden	..	..	..	..	..	..	..	..
Switzerland	..	..	..	..	..	..	..	..
Turkey	x	x	x	x	x	x	x	x
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; | Break in series; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Total investment in inland transport infrastructure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	487.3	242.4	211.1	181.4	234.9	193.4	179.8	89.1
Armenia	137.4	79.2	56.9	50.4	34.9	78.8	90.1	96.1
Australia	11 480.8	14 812.2	18 966.8	22 503.1	17 709.9	14 758.9	13 274.9	14 502.3
Austria	2 732.0	2 337.0	2 448.0	2 018.0	2 022.0	2 030.0	2 006.0	1 969.0
Azerbaijan	..	..	..	1 605.9	2 341.7	1 675.1	955.2	540.1
Belarus	..	..	..	..	..	..	..	..
Belgium	1 767.3	1 878.5 |	1 695.1	2 038.4	1 954.8	1 628.0 |	2 075.0 p	1 994.1
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	150.8	411.1	434.1	501.6	483.2	420.3	555.0	554.2
Canada	11 383.4	16 076.1	15 935.6	15 800.9	14 097.5	6 071.2 |	6 699.8	6 535.7 p
China	181 424.8	227 359.4	220 055.1	290 815.0	330 627.4	395 289.6	526 092.6	..
Croatia	1 010.9	601.3	549.7	543.8	609.1	410.2	298.4	241.7
Czech Republic	2 784.9	2 340.5	1 762.4	1 275.1	989.3	1 067.8	2 065.4	1 540.5
Denmark	1 070.5	1 333.0	1 914.9	2 239.4	2 043.1	2 260.9	2 394.8	2 284.5
Estonia	156.0	172.0	252.0	261.5	250.6	186.0	219.3	189.3
Finland	1 285.0	1 280.0	1 329.0	1 580.0	1 756.0	1 883.0	1 812.0	1 808.0
France	18 357.1	18 532.7	18 142.2	19 493.3	21 418.6	18 332.6	16 935.8	15 458.4
Georgia	310.1	316.1	514.4	421.3	299.4	301.0	282.3	291.2
Germany	17 202.0	16 147.0	16 496.0	16 345.0	16 805.0	17 065.0	17 270.0	18 125.0
Greece	2 258.0	1 606.0	1 495.0	1 265.0	2 277.0	1 778.5 e	1 604.3 e	..
Hungary	1 885.9	1 112.9 |	647.0	625.1	1 023.9	1 865.1	1 949.0	1 136.2
Iceland	120.9	79.3	38.7 |	37.9	41.8	45.3	67.4	..
India	9 531.0	11 509.3	10 561.1	12 284.2	14 403.8	18 551.3	26 570.0	..
Ireland	..	..	..	..	..	..	..	..
Italy	11 355.0	8 204.0	8 631.0	7 397.0	7 080.0	8 960.0	8 521.0	..
Japan	46 808.9	47 072.1	46 021.3	49 103.9	42 321.3	38 476.1	37 023.6	..
Korea	16 817.9	16 050.1	14 181.4	16 745.2	17 175.6	17 080.1	21 763.5	..
Latvia	195.0	204.0	275.0	292.0	276.0	324.0	412.0	214.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	516.0	530.0	461.0	383.0	393.0	491.0	439.0	427.0
Luxembourg	321.2	340.1	373.7	339.1	366.1	395.7	498.7	..
Malta	3.7	12.6	17.3	26.7	11.1	38.5	..	..
Mexico	3 458.2	4 371.9	4 565.7	4 576.0	4 879.3	5 881.2	5 446.4	4 739.2
Moldova, Republic of	21.9	21.0	16.0	50.8	49.0	43.4	..	..
Montenegro, Republic of	23.0	18.0	15.0	18.0	20.0	9.0	12.0	..
Netherlands	3 502.0	3 649.0	3 686.0	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	..	..	..	..	..	..	..	..
Norway	2 846.9	3 153.3	3 372.8	3 976.9	4 683.0	5 022.3	4 840.9	..
Poland	6 012.7	7 224.5	9 277.7	4 813.9	2 727.6	1 835.3	2 511.2	3 402.0
Portugal	1 316.0 |	1 915.0	..	363.0 p	282.0 p	..	..	..
Romania	3 818.8	3 443.5	3 964.0	3 490.1	3 205.7	3 084.4	3 698.1	2 865.8
Russian Federation	12 877.7	15 321.2	18 597.6	20 705.6	19 729.4	14 861.7	11 179.4	12 500.9
Serbia, Republic of	276.5	262.2	371.8	284.2	304.1	366.5	610.5	607.9 p
Slovak Republic	839.0 |	618.0	722.0	528.0	685.0	826.0	1 429.3	877.3
Slovenia	478.0	352.0	218.0	174.0	244.0	398.0	478.0	184.4
Spain	18 194.0	15 520.0	13 519.0	10 666.0	7 356.0	7 400.0	7 024.0	5 431.0 p
Sweden	2 892.2	3 098.3	3 312.2	3 542.0	3 117.2	3 052.2	3 249.1 |	3 263.9
Switzerland	5 885.2	6 450.6	7 232.6	7 344.2	7 397.0	7 197.4	..	..
Turkey	4 226.3	6 640.8	6 730.8	6 310.4	8 480.5	8 024.4	10 137.8	9 047.9
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	12 873.8	12 870.0	13 097.7	14 323.4	14 456.3	17 939.8	23 395.3 |	22 186.4
United States	66 496.1	70 900.7	68 765.5	74 961.9	72 271.5	75 842.1	97 158.4	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Investment in sea port infrastructure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	2.8	3.9	9.9	8.8	1.1	2.2	5.8	2.6
Armenia	x	x	x	x	x	x	x	x
Australia	1 170.5	1 812.2	3 515.8	5 758.4	4 636.5	3 210.8	1 206.2	851.9
Austria	x	x	x	x	x	x	x	x
Azerbaijan	..	..	59.2	48.5	420.3	260.0	80.2	40.8
Belarus	x	x	x	x	x	x	x	x
Belgium	219.0	230.0 |	241.0	236.0	197.0	150.0	108.0	90.9
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	8.2	5.1	4.6	3.1	2.6	14.8	10.2	10.2
Canada	299.0	319.1	249.3 |	432.0	578.0	520.7	691.7	704.1 p
China	..	..	..	..	..	..	..	..
Croatia	76.7	51.4	62.6	95.9	74.3	69.7	..	..
Czech Republic	x	x	x	x	x	x	x	x
Denmark	66.2	49.4	62.3	64.9	150.8	68.0	64.4	..
Estonia	75.0	39.0	18.0	8.6	5.9	6.7	12.2	6.1
Finland	100.0	69.0	77.0	56.0	40.0	44.0	55.0	114.0
France	274.0	213.0	215.0	228.0	323.0	340.1	307.5	353.6
Georgia	23.6	24.5	5.9	20.1	24.0	22.4	7.8	8.3
Germany	685.0	965.0	925.0	890.0	780.0	450.0	460.0	430.0
Greece	107.0	73.0	25.0	24.0	33.0	24.8 e	20.4 e	..
Hungary	x	x	x	x	x	x	x	x
Iceland	19.9	14.5	16.9	15.2	15.5	15.2	20.0	..
India	65.4	71.9	61.0	62.2	39.5	35.3	77.3	..
Ireland	12.0	6.0	16.0	11.0	11.0	11.0	11.0	11.0
Italy	1 278.0	1 345.0	1 268.0	1 343.0	1 126.0	1 168.0	1 059.0	..
Japan	4 655.6	2 168.5	2 287.0	3 281.1	2 287.8	1 916.5	2 106.1	2 622.4
Korea	1 200.6	1 215.9	1 059.8	1 129.8	1 052.1	1 077.4	1 326.3	1 339.2
Latvia	..	..	..	..	..	..	..	..
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	16.0	21.0	27.0	28.0	83.0	22.0	17.0	13.0
Luxembourg	x	x	x	x	x	x	x	x
Malta	13.0 e	3.0	6.0	8.0	4.0	5.0	..	..
Mexico	382.8	486.6	542.8	666.6	653.5	629.3	695.3	542.6
Moldova, Republic of	3.1	5.4	4.2	..	..	3.9	..	..
Montenegro, Republic of	2.0	3.0	3.0	1.0	25.0	19.0	7.0	..
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	x	x	x	x	x	x	x	x
Norway	81.1	19.0	8.2	11.4	28.7	12.8	10.5	..
Poland	4.2	27.0	63.6	153.9	93.9	..	..	..
Portugal	100.0	112.0	83.0	62.0	34.0	87.8	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	182.6	115.2	326.6	86.4	147.6	138.8	49.3	178.2
Serbia, Republic of	x	x	x	x	x	x	x	x
Slovak Republic	x	x	x	x	x	x	x	x
Slovenia	54.0	13.0	6.0	5.0	8.0	23.0	16.0	25.0
Spain	2 508.0	2 247.0	1 789.0	1 245.0	830.0	873.0	907.0	1 053.0 p
Sweden	72.4	107.3	88.4	69.3	101.3	103.8	81.2	..
Switzerland	x	x	x	x	x	x	x	x
Turkey	21.4	17.2	35.4	73.2	45.1	10.3	8.4	53.6
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Investment in airport infrastructure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Armenia	..	..	..	..	..	..	..	..
Australia	..	..	..	..	..	..	..	..
Austria	221.0	174.0	..	..	..	..	..	..
Azerbaijan	28.6	200.9	163.8	278.2	270.6	78.7	349.8	5.7
Belarus	..	..	..	..	..	..	..	..
Belgium	116.0	30.0 |	34.0	74.0	93.0	107.0	127.0	109.3
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	1.0	1.5	1.5	9.7	5.1	5.1	4.6	4.6
Canada	731.1	607.4	701.5	952.7	1 154.6	1 032.1	1 053.2	980.0
China	6 373.6	9 953.5	9 302.4	13 853.5	15 977.2	17 548.6	26 633.2	..
Croatia	27.9	28.1	18.6	15.6	16.1	77.9	139.7	175.9
Czech Republic	92.3	81.4	40.0	47.2	55.6	36.0	36.4	65.1
Denmark	92.0	47.9	31.1	30.8	79.6	22.5	9.5	..
Estonia	19.0	3.0	6.0	0.5	1.0	0.1	0.0	13.8
Finland	76.0	45.0	44.0	45.0	35.0	86.0	78.9	183.0
France	693.4	758.6	949.0	938.6	744.5	702.4	700.6	972.0
Georgia	0.1	8.5	9.8	38.5	12.8	6.4	11.2	57.9
Germany	1 510.0	1 480.0	1 815.0	1 390.0	930.0	770.0	850.0	900.0
Greece	51.0	38.0	49.0	60.0	49.0	52.9 e	43.5 e	..
Hungary	56.9	50.6	37.9	25.8	11.9	7.6	10.2	17.8 p
Iceland	5.3	1.9	1.7	1.9	1.1	0.3	0.5	..
India	132.6	207.7	188.9	875.6	781.5	720.9	356.4	..
Ireland	509.0	243.0	83.0	..	..	..	..	..
Italy	117.0	634.0	184.0	98.0	87.0	123.0	148.0	..
Japan	2 537.8	2 361.1	1 328.3	1 359.2	1 130.8	1 332.5	1 365.1	1 633.3
Korea	33.5	42.9	44.0	46.3	55.6	65.9	83.0	..
Latvia	3.0	3.0	6.0	9.0	38.0	50.0	42.0	14.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	29.0	8.0	14.0	3.0	7.0	6.0	6.0	2.0
Luxembourg	18.8	6.7	12.5	11.0	0.2	0.5	1.9	..
Malta	..	..	..	..	..	..	..	..
Mexico	178.9	270.7	226.3	202.0	197.0	222.2	1 573.1	2 081.6
Moldova, Republic of	3.6	0.0	1.8	..	0.1	0.0	..	..
Montenegro, Republic of	2.0	28.0	4.0	2.0	..	..	3.0	..
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	0.0	0.1	101.5	0.2	0.1	0.2	0.0	0.5
Norway	251.7	203.1	158.2	475.7	484.8	296.5	265.8	..
Poland	63.3	131.9	205.6	146.3	153.4	236.8	302.4	69.9
Portugal	151.0	127.0 |	102.0	64.0	53.0	45.0	80.0	66.5
Romania	6.1	0.9	2.1	21.1	19.2	28.6	38.7	22.3
Russian Federation	268.7	470.0	435.0	666.5	783.0	877.8	851.7	594.5
Serbia, Republic of	1.2	0.7	0.3	0.3	3.0	1.1	0.2	3.6 p
Slovak Republic	56.0	70.0	33.0	31.0	4.0	5.0	4.2	4.8
Slovenia	13.0	7.0	3.0	4.0	4.0	1.0	1.0	0.0
Spain	1 773.0	1 744.0	1 235.0	943.0	585.0	363.0	293.0	377.0 p
Sweden	86.9	78.8	126.4	404.1	289.3	114.7	131.3	240.2
Switzerland	168.9	210.5	327.4	264.7	294.1	293.9	213.6	351.3
Turkey	309.1	429.9	430.9	433.9	519.2	503.4	1 437.7	2 250.4
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

Rail infrastructure maintenance expenditure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	..	..	..	..	..	..	..	..
Armenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Australia	..	..	..	..	..	..	..	..
Austria	348.0	344.0	451.0	480.0	497.0	504.0	503.0	535.0
Azerbaijan	29.6	22.2	18.9	24.9	29.5	34.5	33.5	21.5
Belarus	..	..	..	..	..	..	..	..
Belgium	..	295.0	312.0	311.0	329.0	333.0	313.0	311.0
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	38.3	35.8	32.7	37.3	41.9	49.6	32.7	32.7
Canada	499.6	642.5	705.1	755.0	738.8	850.8	957.3	799.9 p
China	..	..	..	..	..	..	..	..
Croatia	76.4	89.9	86.8	102.2	102.1	105.7	100.7	87.7
Czech Republic	372.1	359.1	364.5	353.0	377.6	423.6	661.1	576.9
Denmark	..	..	..	..	..	..	..	..
Estonia	..	..	..	..	..	..	..	..
Finland	196.0	195.0	197.0	181.0	201.0	194.0	206.0	216.0
France	3 730.0	3 770.0	3 804.0	3 983.0	3 884.0	3 115.0	3 245.8 e	3 274.7
Georgia	..	20.5	18.4	20.2	22.5	22.9	21.8	20.4
Germany	..	..	..	..	..	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	398.4	439.7	435.1	434.8	418.2	490.2	473.3	550.0
Iceland	x	x	x	x	x	x	x	x
India	12 444.2	14 916.5	15 326.7	16 388.7	16 900.3	17 805.6	20 958.4	21 595.2
Ireland	..	..	..	..	..	..	..	..
Italy	7 832.0	7 829.0	7 675.0	7 477.0	7 205.0	7 194.0	1 741.0	..
Japan	..	..	..	..	..	..	..	..
Korea	754.2	885.8	836.9	981.8	1 036.3	1 153.4	1 455.1	..
Latvia	133.0	98.0	109.0	112.0	110.0	119.0	117.0	108.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	132.0	143.0	151.0	156.0	153.0	155.0	161.0	167.0
Luxembourg	125.5	120.0	124.4	132.4	139.5	142.7	152.6	..
Malta	x	x	x	x	x	x	x	x
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	..	..	..	..	..	..	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	1 410.0	1 690.0	1 798.0	1 798.0	1 798.0	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	..	..	..	..	..	..	..	..
Norway	541.7	677.9	730.5	756.5	713.0	800.9	837.3	..
Poland	157.1	212.8	238.7	307.3	387.2	614.2	578.8	729.4
Portugal	127.0	135.0	..	..	..	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	15.8	13.5	17.4	15.8	9.0	9.2	8.8	7.0 p
Slovak Republic	15.0 |	12.0	6.0	9.0	7.0	8.0	10.5	9.5
Slovenia	102.0	68.0	81.0	87.0	71.0	101.0	110.0	89.8
Spain	..	..	..	..	..	..	..	..
Sweden	589.9	723.2	750.3	851.1	924.5	976.6	910.5	954.1
Switzerland	534.5	586.7	666.9	728.4	728.7	708.1	816.8	805.4
Turkey	177.6	222.8	194.9	192.7	172.5	171.0	174.1	171.7
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	2 182.3	2 084.3	1 840.2	1 951.6	2 013.0	1 052.2	5 464.9 |	5 329.7
United States	..	..	..	..	..	..	..	..

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Road infrastructure maintenance expenditure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	8.7	6.9	7.7	6.7	8.7	15.3	8.4	13.0
Armenia	9.9	11.0	10.3	10.7	10.1	10.1	11.2	11.6
Australia	..	..	..	..	..	..	..	..
Austria	516.0	559.0	494.0	517.0	559.0	667.0	692.0	697.0
Azerbaijan	24.7	23.4	26.5	34.3	31.2	31.2	23.0	18.9
Belarus	..	..	..	..	..	..	..	..
Belgium	111.0	184.0	156.0	145.0	147.0	206.0	457.0	528.0
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	69.0	99.7	70.6	102.8	95.6	92.5	92.5	92.5
Canada	6 550.6	8 693.7	5 818.6	6 229.8	3 942.6	4 727.9	5 351.8	4 906.8 p
China	..	..	..	..	..	..	..	..
Croatia	143.8	195.0	212.1	186.5	209.0	257.4	245.1	234.4
Czech Republic	578.3	669.8	569.7	570.7	513.1	587.1	684.4	767.3
Denmark	866.3	1 058.0	880.9	944.5	920.1	795.9	807.8	919.8
Estonia	39.0	38.0	39.0	44.3	47.2	46.3	47.5	43.6
Finland	684.0	667.0	658.0	525.0	511.0	506.0	508.9	544.0
France	2 601.0	2 431.0	2 746.0	2 851.0	2 904.0	2 760.0	2 598.2	2 430.9
Georgia	11.1	9.3	13.4	15.1	14.1	15.6	15.5	17.9
Germany	..	..	..	..	..	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	454.0	328.6 e	256.5	295.8	370.2	272.8	282.2	292.6
Iceland	30.0	28.9	29.0	29.7	27.8	32.3	43.4	..
India	6 254.5	9 380.2	9 299.0	7 763.6	7 040.9	7 232.1	7 488.8	..
Ireland	170.0	165.0	159.0	139.0	128.0	85.0	82.0	..
Italy	6 008.0	6 437.0	6 220.0	7 196.0	9 134.0	9 564.0	9 066.0	..
Japan	13 529.0	13 962.8	15 681.5	17 611.0	16 256.9	14 088.9	14 437.4	..
Korea	1 402.7	1 445.0	1 499.5	1 605.6	1 665.0	1 647.8	2 206.6	..
Latvia	131.0	113.0	125.0	120.0	133.0	154.0	171.0	175.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	125.0	160.0	153.0	123.0	127.0	143.0	159.0	152.0
Luxembourg	29.6	33.8	36.9	33.7	41.1	39.6	39.2	..
Malta	24.8	24.9	27.1	24.2	24.9	17.2	..	..
Mexico	671.4	801.8	821.5	823.7	1 098.1	1 124.2	1 091.0	1 093.9
Moldova, Republic of	17.3	37.0	36.4	55.1	64.0	72.0	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	827.0	1 209.0	323.0	..	..	..	..	..
New Zealand	607.0	719.8	789.1	948.0	885.2	969.1	951.8	..
North Macedonia	12.3	15.6	14.6	12.5	10.8	10.0	10.1	12.7
Norway	1 220.6	1 361.1	1 615.4	1 746.6	1 841.0	1 990.0	1 948.3	..
Poland	2 339.8	2 636.3	2 679.5	428.0	438.2	383.1	415.5	418.7
Portugal	124.0 |	102.0	..	165.0	174.0	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	258.9	229.0	205.4	208.9	129.2	143.0	163.0	180.9 p
Slovak Republic	192.0	175.0	160.0	193.0	204.0	181.0	201.0	215.0
Slovenia	151.0	137.0	122.0	120.0	123.0	113.0	126.0	138.0
Spain	..	..	..	..	..	..	..	..
Sweden	786.8	873.8	856.5	958.8	1 043.6	1 017.5	1 183.6 |	1 130.0
Switzerland	1 817.3	1 998.3	2 235.0	2 413.5	2 402.3	2 420.5	..	..
Turkey	410.7	360.0	674.5	699.9	630.1	558.0	239.3	230.1
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	4 336.4	3 917.3	3 444.3	3 450.6	3 145.4	2 881.2	3 165.7	2 844.7
United States	23 112.8	29 785.2	29 892.2	33 972.5	34 208.0	35 926.4	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Inland waterway infrastructure maintenance expenditure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	..	..	..	..	..	..	..	..
Armenia	x	x	x	x	x	x	x	x
Australia	x	x	x	x	x	x	x	x
Austria	..	..	11.0	12.0	17.0	19.0	14.0	12.0
Azerbaijan	..	..	..	..	..	..	..	..
Belarus	..	..	..	..	..	..	..	..
Belgium	131.0	65.0	58.0	71.0	66.0	27.0	82.0	85.0
Bosnia-Herzegovina	x	x	x	x	x	x	x	x
Bulgaria	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0
Canada	..	..	..	..	..	..	..	..
China	..	..	..	..	..	..	..	..
Croatia	1.2	0.7	0.8	1.2	1.2	..	..	..
Czech Republic	1.8	1.5	1.8	2.9	4.6	4.5	7.5	6.2
Denmark	x	x	x	x	x	x	x	x
Estonia	x	x	x	x	x	x	x	x
Finland	26.0	17.0	20.0	15.0	16.0	17.0	16.3	18.0
France	61.0	60.0	61.0	61.0 e	61.0 e	60.0 e	59.8 e	59.6
Georgia	x	x	x	x	x	x	x	x
Germany	..	..	..	..	..	..	..	..
Greece	x	x	x	x	x	x	x	x
Hungary	0.9	3.2 e	1.6	0.8	0.9	1.3	1.4	2.7
Iceland	x	x	x	x	x	x	x	x
India	..	..	..	..	..	..	..	..
Ireland	x	x	x	x	x	x	x	x
Italy	82.0	81.0	78.0	77.0	113.0	125.0	106.0	..
Japan	x	x	x	x	x	x	x	x
Korea	x	x	x	x	x	x	x	x
Latvia	x	x	x	x	x	x	x	x
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0
Luxembourg	0.2	0.3	0.2	0.3	0.2	0.2	0.1	..
Malta	x	x	x	x	x	x	x	x
Mexico	x	x	x	x	x	x	x	x
Moldova, Republic of	0.6	0.0	..	..	..	..	..	..
Montenegro, Republic of	x	x	x	x	x	x	x	x
Netherlands	693.0	544.0	343.0	..	..	..	..	..
New Zealand	x	x	x	x	x	x	x	x
North Macedonia	x	x	x	x	x	x	x	x
Norway	x	x	x	x	x	x	x	x
Poland	3.0	7.8	16.5	7.6	21.0	5.5	..	..
Portugal	..	..	0.0	1.0	1.0	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	10.5	13.2	23.0	17.6	16.5	17.3	29.8	28.7 p
Slovak Republic	2.0	2.0	2.0	3.0	4.0	9.0	3.7	0.3
Slovenia	x	x	x	x	x	x	x	x
Spain	x	x	x	x	x	x	x	x
Sweden	x	x	x	x	x	x	x	x
Switzerland	..	..	..	..	..	..	..	..
Turkey	x	x	x	x	x	x	x	x
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Sea port infrastructure maintenance expenditure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	..	..	..	..	..	..	..	..
Armenia	x	x	x	x	x	x	x	x
Australia	..	..	..	..	..	..	..	..
Austria	x	x	x	x	x	x	x	x
Azerbaijan	..	..	..	7.9	..	1.8	3.5	2.4
Belarus	x	x	x	x	x	x	x	x
Belgium	135.0	..	..	..	..	..	..	..
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	4.6	1.0	0.5	0.5	1.0	2.0	1.5	1.0
Canada	138.2	150.8	263.9 |	1 167.5	1 173.6	1 038.4	1 376.2	1 280.6 p
China	..	..	..	..	..	..	..	..
Croatia	3.7	2.7	3.4	4.0	4.4	3.0	..	..
Czech Republic	x	x	x	x	x	x	x	x
Denmark	..	..	..	..	..	..	..	..
Estonia	..	..	..	..	..	..	..	..
Finland	107.0	106.0	122.0	101.0	112.0	101.0	76.0	91.0
France	48.0	53.0	53.0	53.0 e	53.0 e	53.0 e	53.5 e	50.7
Georgia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Germany	..	..	..	..	..	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	x	x	x	x	x	x	x	x
Iceland	..	..	..	..	..	..	..	..
India	131.6	191.7	147.6	130.7	172.3	183.9	260.4	..
Ireland	..	..	..	..	..	..	..	..
Italy	1 287.0	1 098.0	1 447.0	1 628.0	1 263.0	2 609.0	2 538.0	..
Japan	..	..	..	..	..	..	..	..
Korea	112.0	100.0	84.2	99.5	102.2	111.2	135.7	136.3
Latvia	..	..	..	..	..	..	..	..
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	2.0	7.0	2.0	3.0	3.0	4.0	7.0	4.0
Luxembourg	x	x	x	x	x	x	x	x
Malta	..	1.0	1.0	1.0	0.0	2.0	..	..
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	..	..	..	..	..	..	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	x	x	x	x	x	x	x	x
Norway	..	..	..	..	..	..	..	..
Poland	9.7	9.5	15.3	15.3	19.5	..	..	..
Portugal	1.0	1.0	4.0	3.0	3.0	2.6	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	x	x	x	x	x	x	x	x
Slovak Republic	x	x	x	x	x	x	x	x
Slovenia	2.0	2.0	3.0	3.0	2.0	3.0	2.0	4.0
Spain	..	..	..	..	..	..	..	..
Sweden	22.8	27.4	27.4	19.6	19.8	18.0	23.2	..
Switzerland	x	x	x	x	x	x	x	x
Turkey	..	..	..	..	..	..	..	..
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; | Break in series; e Estimated value; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Airport infrastructure maintenance expenditure

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Armenia	..	..	..	..	..	..	..	..
Australia	..	..	..	..	..	..	..	..
Austria	..	..	..	..	..	..	..	..
Azerbaijan	10.6	3.7	6.9	7.5	9.3	9.6	8.0	5.7
Belarus	..	..	..	..	..	..	..	..
Belgium	..	..	..	..	..	..	..	..
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	1.0	1.5	1.5	0.0	2.0	2.0	1.5	1.5
Canada	599.9	706.2	699.3	755.8 |	741.0	720.6	800.6	850.4
China	..	..	..	..	..	..	..	..
Croatia	3.4	2.3	3.5	3.5	4.5	4.5	3.5	4.0
Czech Republic	12.5	13.8	7.0	8.8	15.2	9.0	8.2	11.0
Denmark	..	..	..	..	..	..	..	..
Estonia	..	..	..	..	..	..	..	..
Finland	230.0	240.0	267.0	268.0	251.0	233.0	232.0	240.0
France	..	..	..	..	..	..	..	..
Georgia	0.3	0.3	0.4	1.0	0.7	0.5	0.5	0.4
Germany	..	..	..	..	..	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	6.8	8.2	8.5	8.1	7.6	7.1	7.5	7.7 p
Iceland	..	..	..	..	..	..	..	..
India	167.5	220.2	143.9	166.7	128.6	125.0	136.4	..
Ireland	33.0	34.0	29.0	..	..	..	..	..
Italy	100.0	102.0	95.0	115.0	109.0	93.0	90.0	..
Japan	..	..	..	..	..	..	..	..
Korea	12.4	15.7	15.1	19.0	20.1	36.5	49.6	..
Latvia	..	..	..	..	..	..	..	..
Liechtenstein	x	x	x	x	x	x	x	x
Lithuania	2.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0
Luxembourg	4.8	7.5	7.0	9.7	9.6	9.5	9.4	..
Malta	..	..	..	..	..	..	..	..
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	..	..	..	..	0.1	0.0	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	..	..	..	..	..	..	..	..
Norway	..	..	..	..	..	..	..	..
Poland	4.4	5.0	20.6	64.3	33.6	63.1	96.3	15.4
Portugal	14.0	9.0 |	16.0	..	..	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	0.0	0.0	0.0	1.3	0.0	0.1	0.1	0.0 p
Slovak Republic	3.0	5.0	2.0	3.0	1.0	1.0	1.9	2.4
Slovenia	..	..	..	..	..	..	..	..
Spain	..	..	..	..	..	..	..	..
Sweden	30.9	26.4 |	17.3	17.7	16.4	12.3	13.4	13.2
Switzerland	..	..	..	..	..	..	..	..
Turkey	4.6	6.5	2.6	44.5	32.0	9.6	44.0	25.1
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	..	..	..	..
United States	..	..	..	..	..	..	..	..

.. Not available; | Break in series; x Not applicable; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Total spending on road infrastructure investment and maintenance

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	495.7	248.8	217.9	187.5	242.9	208.0	187.6	102.1
Armenia	94.1	47.5	40.8	37.2	33.3	76.8	89.0	102.0
Australia	..	..	..	..	..	..	..	..
Austria	1 181.0	949.0	797.0	844.0	922.0	1 120.0	1 147.0	1 141.0
Azerbaijan	1 296.7	1 568.9	1 588.3	1 518.4	1 944.8	1 442.5	896.2	517.0
Belarus	..	..	..	..	..	..	..	..
Belgium	286.0	532.0 |	404.0	698.0	734.0	623.0	1 235.0 p	1 338.0
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	170.3	380.9	414.7	490.3	455.1	345.1	345.1	345.1
Canada	17 440.7	24 072.4	20 884.7	20 986.1	17 028.6	9 836.6	10 988.6	10 674.0 p
China	..	..	..	..	..	..	..	..
Croatia	1 052.9	710.3	677.8	665.2	633.2	536.9	483.5	431.7
Czech Republic	2 563.8	2 389.4	1 862.9	1 447.0	1 160.6	1 191.1	1 569.8	1 616.5
Denmark	1 580.1	1 994.6	1 932.8	2 268.2	1 967.0	1 897.4	1 894.2	2 019.2
Estonia	158.0	175.0	197.0	258.1	271.3	216.8	253.7	217.5
Finland	1 606.0	1 557.0	1 631.0	1 653.0	1 659.0	1 744.0	1 751.9	1 813.0
France	16 878.8	16 928.1	15 350.3	16 024.7	15 770.2	13 567.2	12 609.5	11 673.2
Georgia	229.9	242.1	261.0	192.5	250.8	240.1	209.6	220.4
Germany	..	..	..	..	..	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	2 019.2	1 168.8 e	554.5	448.4	770.8	1 511.2	1 529.9	1 095.3
Iceland	150.9	108.2	67.7 |	67.7	69.6	77.6	110.8	..
India	11 061.8	15 739.9	14 915.7	13 971.9	15 516.1	17 005.5	22 596.3	..
Ireland	1 939.0	1 579.0	1 176.0	1 025.0	722.0	723.0	694.0	..
Italy	11 649.0	9 826.0	10 349.0	10 303.0	11 975.0	13 424.0	14 217.0	..
Japan	50 736.0	49 729.1	51 494.0	54 911.8	49 386.1	43 920.8	42 580.8	..
Korea	13 591.4	12 236.4	10 743.0	12 386.3	13 002.2	12 552.4	15 380.9	..
Latvia	263.0	244.0	347.0	310.0	332.0	342.0	374.0	365.0
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	573.0	582.0	496.0	366.0	380.0	367.0	417.0	509.0
Luxembourg	178.1	216.4	258.9	247.1	261.2	243.5	260.1	..
Malta	28.5	37.5	44.5	51.0	36.0	55.8	..	..
Mexico	3 692.0	4 738.9	4 737.3	4 809.0	5 278.1	6 007.5	5 387.2	4 477.3
Moldova, Republic of	30.7	50.8	44.6	95.3	100.2	110.9	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	3 190.0	3 509.0	2 610.0	..	..	..	..	..
New Zealand	1 185.7	1 451.5	1 631.1	1 616.2	1 651.3	1 921.4	2 095.3	..
North Macedonia	116.1	99.2	118.5	83.0	98.3	184.3	176.4	241.3
Norway	3 708.9	4 035.1	4 427.0	5 047.7	5 685.3	5 794.1	5 507.8	..
Poland	7 677.5	9 145.9	11 002.7	4 810.8	2 903.0	2 104.2	2 586.3	3 494.1
Portugal	1 075.0 |	1 613.0	..	439.0 p	385.0 p	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	510.4	457.8	544.4	465.5	408.4	480.0	668.1	674.7 p
Slovak Republic	854.0	517.0	592.0	504.0	564.0	731.0	1 334.8	960.6
Slovenia	557.0	358.0	234.0	222.0	227.0	241.0	228.0	238.0
Spain	..	..	..	..	..	..	..	..
Sweden	2 360.5	2 539.9	2 768.2	3 170.9	3 056.7	2 882.3	3 045.1 |	3 216.3
Switzerland	4 814.2	5 416.7	6 057.5	6 293.9	6 133.7	6 067.8	..	..
Turkey	3 865.6	5 495.4	5 879.1	5 501.8	6 856.2	7 201.8	9 296.1	7 559.7
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	10 903.0	10 400.2	9 009.3	9 008.1	9 175.3	10 726.8	12 233.7	11 452.8
United States	82 468.2	93 321.5	90 321.9	98 456.0	96 623.2	100 420.7	..	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Total inland transport infrastructure investment as a percentage of GDP

Percentage

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	5.6	2.7	2.3	1.9	2.4	1.9	1.8	0.8
Armenia	2.2	1.1	0.8	0.6	0.4	0.9	0.9	1.0
Australia	1.6	1.6	1.8	1.9	1.6	1.4	1.2	1.3
Austria	0.9	0.8	0.8	0.6	0.6	0.6	0.6	0.6
Azerbaijan	..	..	..	3.0	4.2	3.0	2.0	1.6
Belarus	..	..	..	..	..	..	..	..
Belgium	0.5	0.5 |	0.4	0.5	0.5	0.4 |	0.5 p	0.5
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	0.4	1.1	1.1	1.2	1.2	1.0	1.2	1.2
Canada	1.2	1.3	1.2	1.1	1.0	0.4 |	0.5	0.5 p
China	4.9	4.9	4.0	4.4	4.6	5.0	5.3	..
Croatia	2.2	1.3	1.2	1.2	1.4	0.9	0.7	0.5
Czech Republic	1.9	1.5	1.1	0.8	0.6	0.7	1.2	0.9
Denmark	0.5	0.5	0.8 |	0.9	0.8	0.9	0.9	0.8
Estonia	1.1	1.2	1.5	1.5	1.3	0.9	1.1	0.9
Finland	0.7	0.7	0.7	0.8	0.9	0.9	0.9	0.8
France	0.9	0.9	0.9	0.9	1.0	0.9	0.8	0.7
Georgia	4.0	3.6	5.0	3.4	2.5	2.4	2.2	2.2
Germany	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Greece	1.0	0.7	0.7	0.7	1.3	1.0 e	0.9 e	..
Hungary	2.0	1.1 |	0.6	0.6	1.0	1.8	1.8	1.0
Iceland	1.3	0.8	0.4 |	0.3	0.4	0.3	0.4	..
India	1.0	0.9	0.8	0.8	1.0	1.2	1.4	..
Ireland	..	..	..	..	..	..	..	..
Italy	0.7	0.5	0.5	0.5	0.4	0.6	0.5	..
Japan	1.2	1.1	1.0	1.0	1.1	1.1	0.9	..
Korea	2.6	1.9	1.6	1.8	1.7	1.6	1.7	..
Latvia	1.0	1.1	1.4	1.3	1.2	1.4	1.7	0.9
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	1.9	1.9	1.5	1.1	1.1	1.3	1.2	1.1
Luxembourg	0.9	0.8	0.9	0.8	0.8	0.8	1.0	..
Malta	0.1	0.2	0.3	0.4	0.1	0.5	..	..
Mexico	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5
Moldova, Republic of	0.6	0.5	0.3	0.9	0.8	0.7	..	..
Montenegro, Republic of	0.8	0.6	0.5	0.6	0.6	0.3	0.3	..
Netherlands	0.6	0.6	0.6	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	1.6	1.2	1.4	0.9	1.1	2.1	1.9	2.4
Norway	1.0	1.0	0.9	1.0	1.2	1.3	1.4	..
Poland	1.9	2.0	2.4	1.2	0.7	0.4	0.6	0.8
Portugal	0.8 |	1.1	..	0.2 p	0.2 p	..	..	..
Romania	3.1	2.7	3.0	2.6	2.2	2.1	2.3	1.7
Russian Federation	1.5	1.3	1.3	1.2	1.1	1.0	0.9	1.1
Serbia, Republic of	0.9	0.9	1.1	0.9	0.9	1.1	1.8	1.8 p
Slovak Republic	1.3 |	0.9	1.0	0.7	0.9	1.1	1.8	1.1
Slovenia	1.3	1.0	0.6	0.5	0.7	1.1	1.2	0.5
Spain	1.7	1.4	1.3	1.0	0.7	0.7	0.7	0.5 p
Sweden	0.9	0.8	0.8	0.8	0.7	0.7	0.7 |	0.7
Switzerland	1.5	1.5	1.4	1.4	1.4	1.3	..	..
Turkey	0.9	1.1	1.1	0.9	1.2	1.1	1.3	1.2
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	0.8	0.7	0.7	0.7	0.7	0.8	0.9 |	0.9
United States	0.6	0.6	0.6	0.6	0.6	0.6	0.6	..

.. Not available; | Break in series; e Estimated value; p Provisional data
Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.
Source: ITF Transport statistics

Capital value of inland transport infrastructure assets

Million euros

	2009	2010	2011	2012	2013	2014	2015	2016
Albania	..	..	..	..	..	..	..	..
Armenia	77	48	273	34	19	36	18	12
Australia	111 177 e	141 594 e	153 793 e	171 543 e	156 167 e	146 884 e	149 959 e	..
Austria	..	..	..	..	..	..	..	..
Azerbaijan	..	..	..	..	..	..	..	..
Belarus	..	..	..	..	..	..	..	..
Belgium	..	..	..	..	19 687	20 332	20 599	21 535
Bosnia-Herzegovina	..	..	..	..	..	..	..	..
Bulgaria	..	..	..	..	..	..	..	..
Canada	..	..	..	..	..	..	..	..
China	..	..	..	..	..	..	..	..
Croatia	..	..	..	..	..	..	..	..
Czech Republic	..	..	..	..	..	..	..	..
Denmark	..	..	..	..	..	..	..	..
Estonia	166	168	211	222	294	290	283	281
Finland	37 572	38 728	41 068	42 948	43 746	44 718	44 227	44 437
France	676 774	679 910	682 756	685 318	688 429	690 433	692 077	693 111
Georgia	..	..	..	..	..	..	..	..
Germany	17 953	16 877	17 130	17 046	17 717	..	..	..
Greece	..	..	..	..	..	..	..	..
Hungary	..	..	..	..	..	..	..	..
Iceland	..	..	..	..	..	..	..	..
India	..	..	5 974	7 149	6 405	9 045	10 160	11 136
Ireland	..	..	..	..	..	..	..	..
Italy	..	..	..	..	..	..	..	..
Japan	..	..	..	..	..	..	..	..
Korea	..	..	..	..	..	..	..	..
Latvia	4 295	4 937	7 172	7 987	6 994	6 677	7 168	..
Liechtenstein	..	..	..	..	..	..	..	..
Lithuania	..	..	..	..	..	..	2 994	3 040
Luxembourg	..	..	..	..	..	..	..	..
Malta	..	..	..	..	..	..	..	..
Mexico	..	..	..	..	..	..	..	..
Moldova, Republic of	..	..	..	..	..	..	..	..
Montenegro, Republic of	..	..	..	..	..	..	..	..
Netherlands	..	..	..	..	..	..	..	..
New Zealand	..	..	..	..	..	..	..	..
North Macedonia	3 347 e	3 427 e	3 447 e	3 428 e	3 447 e	3 479 e	3 464 e	3 464 e
Norway	41 839	48 736	54 254	60 319	62 074	68 515	73 615	..
Poland	..	..	..	..	..	..	..	..
Portugal	..	..	..	..	..	..	..	..
Romania	..	..	..	..	..	..	..	..
Russian Federation	..	..	..	..	..	..	..	..
Serbia, Republic of	..	..	..	..	..	..	..	..
Slovak Republic	..	..	..	..	..	..	..	..
Slovenia	..	..	..	..	..	..	..	..
Spain	..	..	..	..	..	..	..	..
Sweden	61 824	72 196	80 990	86 886	88 424	85 605	83 030	84 771
Switzerland	45 518	52 056 |	59 146	61 321	60 668	61 948	..	..
Turkey	..	..	..	..	..	..	..	..
Ukraine	..	..	..	..	..	..	..	..
United Kingdom	..	..	..	..	561 954	600 898	672 620	616 297
United States	2 313 716	2 514 772	2 550 909	2 873 367	2 843 171	2 872 366	3 457 733	3 584 132

.. Not available; | Break in series; e Estimated value

Note: Detailed metadata at: http://metalinks.oecd.org/transport/20190130/86ff.

Source: ITF Transport statistics

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