TUMI Transport Outlook 1.5°C

A global scenario to decarbonise transport

TUMI
Transformative Urban Mobility Initiative

UTS Institute for Sustainable Futures

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About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses, and communities to achieve change to support sustainable futures.
ISF acknowledges and respects the Aboriginal and Torres Strait Islander custodians of Australia and the Gadigal people, custodians of the land upon which the UTS City Campus now stands. We continue to value the generations of knowledge that Aboriginal and Torres Strait Islander peoples embed within our university, and we pay our respect to their elders past, present and emerging.

Forword

We will only succeed in avoiding the detrimental effects of climate change by limiting temperature increases to 1.5 C if we drastically reduce greenhouse gas emissions (GHGs) worldwide. The Paris Agreement delivered a long-term vision which outlined a tight carbon budget and a call to action in response to the climate crisis. As all sectors are called on to dramatically reduce their GHG emissions, the transport sector remains one of the greatest challenges to climate policy.

Transport is an international issue – the world is interconnected as never before – for better or worse. The global remaining carbon budget for transport is 110 Gigatons (GT) until 2050. The scope of time we have to act is becoming smaller and smaller. A 110 GT is the figure by which we must measure every decision we make in the transport sector. We still have 99 months until 2030, which is a critical window for action. Will we keep emissions from transport within this budget?

The TUMI Transport Outlook 1.5°C puts down an updated plan to exactly how the transport sector can get there. The TUMI Transport Outlook 1.5°C highlights the urgency of emission cuts by 2050 and acts as a foundation for policy makers in fundamentally transforming the ways people and goods move. Through this data driven backcasting study the potentials to cut down emissions and make transport more sustainable are made available. The study not only shows global and regional transport demand; CO2 emissions for various transport modes and vehicle technology solutions. It also highlights the benefits of avoiding travel, shifting to more sustainable mobility modes (i.e. walking / cycling) as well as mass scale electrification.

The methodology of the study was created from a comprehensive climate model developed in collaboration with 17 leading scientists at the University of Technology Sydney (UTS), two institutes at the German Aerospace Center (DLR), and the University of Melbourne's Climate & Energy College. The design as well as results of the report are shaped by the ongoing dialogue with world leading organisations in sustainable transport. Our gratitude goes to all the colleagues who have helped shape this report.

The TUMI Transport Outlook 1.5°C is pivotal in aligning the transport sector with the Paris Agreement and the 2030 Agenda. We have long known how and where we have to act, this must now be poured into concrete, binding and verifiable action plans. We hope the scenario will inspire bold actions and act as a catalyzer for transforming global transport systems.

Daniel Moser
Management Head TUMI

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Glossary

ADB – Asian Development Bank

AV – Automated vehicle

BAU – Business as usual

BMZ – Federal Ministry for Economic Cooperation and Development

BRT – Bus Rapid Transit

°C – Degrees Celsius

CAF – Development Bank of Latin America

CO_2 – Carbon dioxide

DLR – German Aerospace Center

EV – Electric vehicle

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH

ICE – Internal combustion engine

ICLEI –Local Governments for Sustainability

IEA – International Energy Agencies

ITDP – Institute for Transportation & Development Policy

KFW – Kreditanstalt für Wiederaufbau

LDV – Light duty vehicles

IPCC – Intergovernmental Panel on Climate Change

HST – High Speed Train

LDHV – low density, high value (LDHV) goods

MFT – Multimodal Freight Transport

OECM – One Earth Climate Model

SLOCAT –Partnership on Sustainable Low Carbon Transport

UNFCCC – United Nations Framework Convention on Climate Change

WEO – World Energy Outlook

WRI – World Resource Institute

Executive Summary

The Paris Agreement adopted in December 2015, central aim is to keep global temperature rise this century well below 2°C above pre-industrial levels, and to pursue efforts to limit temperature rise to 1.5°C. Countries and cities around the world have already been rocked by climate change, from unprecedented floods to searing heatwaves and water scarcity, there is an urgent need to implement policies and measures that limit greenhouse gas emissions (GHG) in line with the Paris Agreement and the 2030 Agenda.

The TUMI Transport Outlook 1.5°C outlines the role of the transport sector within these goals as it lays out a plan for exactly how we can achieve the goal of limiting GHG emissions. The transport sector accounts for nearly one-quarter of global energy-related carbon emissions. Climate action in transport is urgently needed because energy-related carbon dioxide (CO_2) emissions are the main driver of climate change (Teske et. al 2019). Transport is responsible for about one quarter of energy related GHG emissions. This is set to increase to one-third by 2050, growing faster than any other sector. Yet a clear-cut path to transformation, one which is backed up with evidence and 'hard' numbers for policymakers around the world, remains missing. To close this gap, TUMI and the University of Technology Sydney have developed a robust scenario study.

This study considers the conditions necessary to achieve the needed emission reductions in the transport sector to align with the Paris Agreement and 2030 Agenda. The study conducts three scenarios: A reference baseline study, in which no changes are implemented in terms of transport, along with a look at those changes that need to take place in order to limit warming to 1.5°C or 2.0°C.

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1. Key Recommendations

The TUMI Transport Outlook detects actionable measures for implementation in three key areas to decarbonise transport in line with the 1.5°C threshold as defined in the Paris Agreement. Avoid or reduce the need to travel, shift to more efficient transport modes, as well as improve efficiency through vehicle technology. The remaining window for significant action to decarbonise is confined to 99 months – from 2021 till 2030.

Condensed from global back-casting efforts on energy intensities, carbon emissions, trends, and drivers in 10 world regions, a potential pathway to a decarbonised transport sector based on five international top-level measures for policymakers:

1. Phase-out internal combustion engines by 2030

To achieve the global decarbonisation of transport, it is fundamental to shift to electric mobility powered by renewable energy. To enable the shift towards electric mobility, a phase-out of newly sold internal combustion engine (ICE) vehicles (passenger cars, vans, 2-3 wheelers, city buses etc.) by 2030 is vital. By setting targets, governments can send strong signals to markets and customers to adopt the new technology. Further, mandating efficiency standards for all vehicle types with a 2% annual efficiency improvement target should be set.

OECD countries have been achieving high electrification rates in road transport at a pace of up to 10 years before non-OECD countries. As technology pick-ups electrification of vehicles will materialize in second- and thirdhand vehicle markets. From 2030 onwards, a rapid and accelerating decline of the share of internal combustion engine vehicles in non-OECD markets can be achieved.

2. Elevate walking and cycling

In order to maintain and extend access levels around the globe while curbing passenger kilometre growth, large- scale expansions of quality infrastructure for bicycles and walking are needed. Higher take up of active mobility is supported by following compact regional und urban planning principles. Under the 1.5°C pathway, levels in which up to 50% of trips made by foot or cycling, as seen in sustainable mobility capitals such as Amsterdam and Copenhagen, should be pursued. To achieve a high-quality cycling network, TUMI estimates that governments should build roughly 2 km of segregated cycling lanes per 1.000 inhabitants.
Special emphasis should be put on rapidly growing cities, as this a) allows for interventions in early phases of urban development and b) will determine mobility patterns over long periods of time.

3. Double public transport capacity by 2030

Even though public transport has seen massive hits in ridership during the COVID-19 pandemic, it continues to play a key role as the backbone of urban and interurban mobility. In order to leverage its potential, the capacity of public transport needs to be doubled, with attention paid to service quality, convenience and affordability to (re-)gain acceptance. The integration of shared mobility and last mile transport services can support intermodality between public transport and individual mobility.

4. Electrify at least 70% of railways by 2030

The 1.5˚C pathway assumes that about one-third of freight transported via trucks are shifted to rail transport systems;whereas the reference scenario assumes that domestic (inland and coastal) navigation will lose both to rail and road transport systems. The share of electric trains needs to be increased under the 1.5˚C scenario, with all diesel locomotives being completely phased out by 2050 across all regions. Therefore, a full electrification (via overhead or battery electric trains) needs to be pursued and by 2030 at least 70% of rail needs to be electrified.

5. Prioritize electricity as the primary fuel for transport

By 2050, all transport fuels need to be carbon neutral and only renewably produced fuels and renewably generated electricity should be in use.
The switch to electric mobility will drastically reduce the global need for oil-based fuels. To meet an increased demand in transport electricity, a corresponding increase in renewable electricity generation should take place. Sustainable biofuels from waste and hydrogen, on the other hand, should be limited to particular and small segments of heavy-duty trucks and machinery, navigation and aviation, as should the use of hydrogen and synthetic fuels to heavy duty machinery, aviation and shipping. Hydrogen and synthetic fuels must be produced by renewable electricity to be compliant with the 1.5°C pathway. The use of biofuel from energy crops is not assumed under the TUMI Transport Outlook pathways.

2. Underlying principles to decarbonise the transport sector

Reduce transport energy demand

Meeting the goal of reducing greenhouse gas emissions in the transport sector as outlined in the 2.0˚C and the 1.5˚C scenarios requires a change in policy, technology, and behaviour. Supportive policy measures encouraging energy efficiency, incentives for smaller cars, and a swapping of vehicle technologies need to be implemented simultaneous to a reduction in transport need as regards the number of kilometres travelled. Compact regional und urban planning principles, which keep spatial distances between living, working, (local) supplies, services, leisure and educational facilities short can reduce the demand for motorised travel significantly. A stronger focus on 'non-energy' travel-modes such as cycling and walking will further reduce transport energy demand.

Shift of transport modes

A shift of transport modes to efficient modes especially in the expanding large metropolitan areas, is required. Policies enabling active mobility and an increased use of public transport will be key to shift passenger transport to efficient modes. Passenger transport needs to shift from road to rail in order to implement the 1.5˚C scenario. This can be accomplished through efficient light rails in cities, commuter trains for short- to medium-distance commutes complimented by high-speed trains that offer convenient services and therefore an alternative to individual car journeys. Similarly, in freight transport a shift from road to rail and from aviation to navigation is key to stay within the 1.5°C scenario.

Improve efficiencies through large-scale electrification

Passenger cars and light commercial vehicles are projected to achieve battery-electric-vehicle (BEV) shares of between 8% and 15% by 2030 globally, with some regions adopting faster than others. This will require a massive build-up of battery production capacity in the coming years. New car sales will be dominated by battery electric passenger vehicles in 2030 under the 1.5˚C scenario. As passenger cars with internal combustion engines (ICEs) have an assumed average lifetime of 15 years, however, the existing car fleet will still predominantly be comprised of ICEs.

Working under the assumption that new ICE passenger cars and buses will not be produced after 2030, the 1.5˚C scenario shows that BEV will dominate the passenger vehicle fleet of 2050. OECD countries and China are assumed to lead the development of BEV and will therefore have the highest shares, whereas Africa and Latin America are expected to have the lowest. Fuel cell-powered passenger vehicles are projected to play a significantly smaller role than battery electric vehicles and will only be used for larger vehicles.

To decarbonize transport the above-mentioned principles can be integrated and are based on the Avoid-Shift-Improve (ASI) framework, which forms a broadly accepted strategy to transforming transport. ASI focuses on avoiding the need for motorized travel and reducing trip lengths, shifting to energy efficient transport modes and improving vehicle efficiency.

3. Calculated Pathways in the TUMI Transport Outlook

All three scenarios are not forecasts but rather projections under different assumptions. They have been calculated based on the IEA World Energy Outlook 2020 Stated Policies scenario and two pathways which limit energy-related carbon emissions from the transport sector within the carbon budget for 2.0°C and 1.5°C (67% likelihood) according to the latest IPCC AR6 carbon budget (IPCC 2021).

The **'Reference'** case, based on the IEA Stated Policies Scenario (IEA 2020) until 2040, with extrapolation to 2050, assumes that there will be no major changes in the global transport sector across all transport modes. Electrification of road transport will remain at a relatively low level and there will be no major shift from individual to public transport and active mobility (cycling & walking). Growth in the share of the commercial road vehicle fleet and of the fleet of two- and three-wheel vehicles with electric powertrains will be small, as will the increase in further rail electrification. Aviation and navigation (shipping) will remain fully dependent on conventional kerosene and diesel, respectively. The results of the Reference case are within the same order of magnitude as the IEA scenario, but does not claim to model all results exactly.

The **2.0°C scenario**: Sees a cumulative carbon budget of 130 Gt CO_2 between 2020 and 2050 for the global transport sector. Minimal progress in electrification is assumed through 2025, with a strong increase towards 2030, encouraged by purchase incentives, carbon pricing, EV credit systems, and tightened CO_2 fleet emission targets. OECD will take the lead in implementing electric mobility, leading to the decarbonisation of the entire sector. This scenario also assumes supportive policy measures encouraging energy efficiency, electrification and the use of public transport to be implemented by 2030.

The **1.5°C scenario**: Assumes the same technical and behavioural change measures as the 2.0°C scenario, but implementation will be faster, with a global cumulative carbon budget of 110 Gt CO_2 until 2050. An earlier and more rapid ramp-up of electric powertrain penetration is required, as are supportive policy measures encouraging energy efficiency, electrification and the use of public transport, which must be implemented by 2025. 'Active mobility' policies that encourage cycling and walking, as well as measures that reduce the need for long work commutes are needed to achieve the reduction in global transport demand.

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4. Carbon budget

The remaining carbon budget for a 1.5°C compatible transport sector globally equates with 3 years of current global energy related carbon emissions.

The TUMI Transport Outlook aims to remain with a clearly defined carbon budget to achieve the Paris Climate Agreement. The global carbon budget for the transport sector – based on the presented analysis – is estimated with 110 Gt CO2 between 2020 and 2050 – about 28% of the remaining carbon budget of 400 Gt CO2. Most of this carbon budget – 20% to 25% of the total global carbon budget – is estimated to be required for the road transport sector.

Table 1. Global Cumulative energy-related CO2 emissions [GtCO2] between 2020 and 2050 under the 1.5°C for the four main sectors: Buildings, industry, power generation and transport

Cumulative energy-related CO_2 emissions [$GtCO_2$]		
Global		Transport Sector Share of cumulative emissions 2020-2050
	2020–2050	[%]
Industry	**77**	**19%**
• Cement	9	2%
• Steel	19	5%
Transport (including power for transport)	**110**	**28%**
• Aviation (incl. international)	11	3%
• Navigation (incl. international)	14	3%
• Rail	3	1%
• Road	82	21%
Power (excluding power for transport)	**107**	**27%**
Building/Other sectors	**93**	**23%**
Other Conversions & losses	**13**	**3%**
Total Actual CO_2 Emissions	400	100%

Carbon dioxide emissions are calculated on the basis of the primary energy fuel demand for oil and gas and the total electricity demand in the transport sector. In regard to fossil fuels, the primary energy demand for each transport mode includes all losses. For the electricity demand of battery-electric vehicles, electric train and the production of synthetic and hydrogen fuels with electricity, the CO2 emissions are calculated with the regional CO2 intensity for the year of calculation under the same scenario.

Carbon dioxide under three scenarios

The global energy related carbon dioxide emissions have to be reduced drastically in order to avoid increasing emissions. The following figure 1 contrasts the two 1.5˚C and 2˚C scenarios against the Reference scenario. Through urban policies, electrification and the additional measures mentioned above, the global transport sector can be decarbonised completely.

Global: Transport energy-related carbon dioxide until 2050

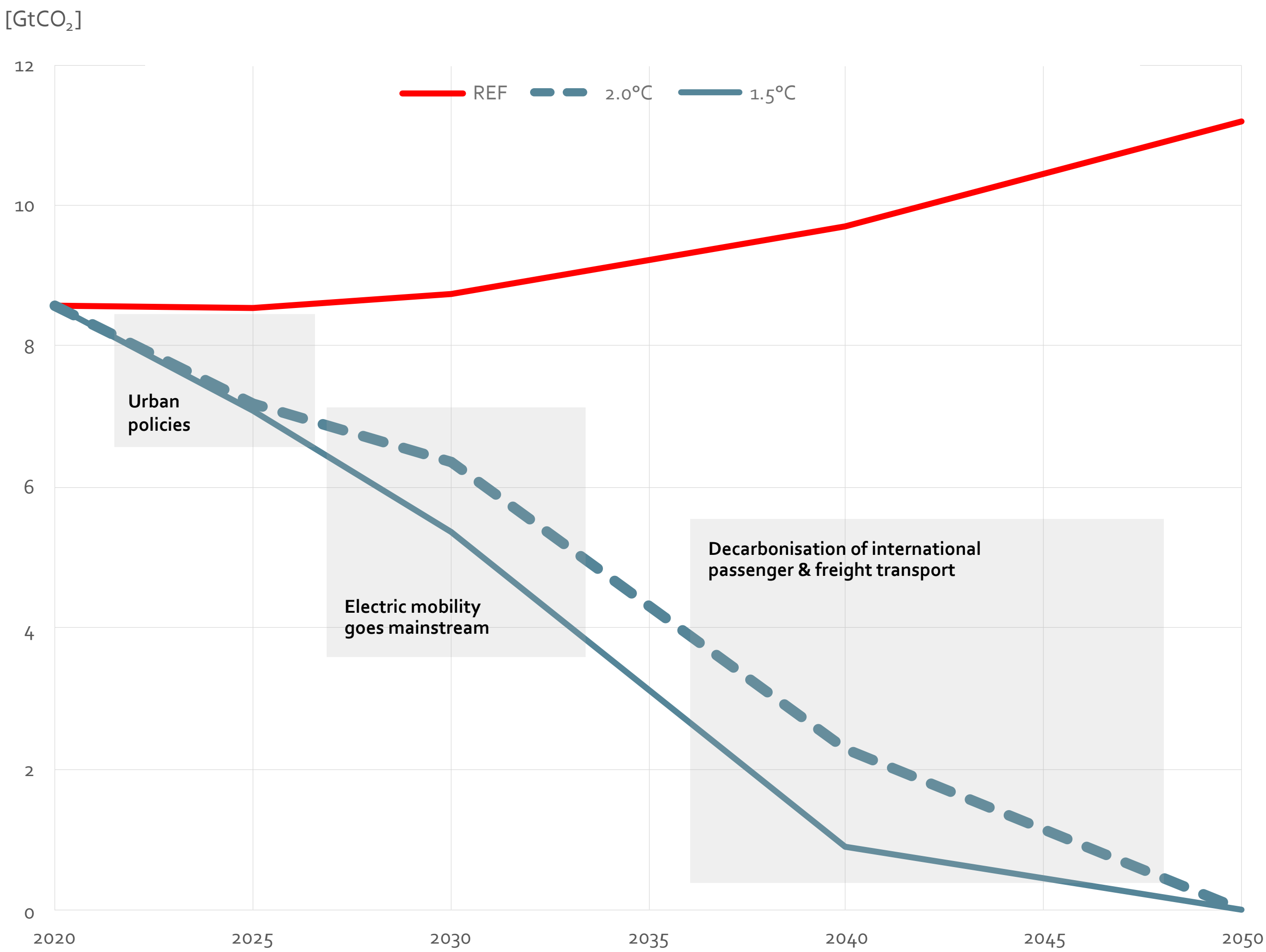

Figure 1. Global: Transport energy related carbon dioxide emissions until 2050

Regional breakdown

Energy-related CO_2 emissions of the transport sector vary significantly by region and OECD countries have by far the highest emissions – both in total and in relation to the population in those countries. OECD North America would emit around 63 $GtCO_2$ between 2020 and 2050 under the reference case – a pathway that assumes no major changes in the transport sector over the next 30 years.

Compared to the global carbon budget, to stay with a 67% likelihood under 1.5˚C of 400 $GtCO_2$ for the same timeframe, the global transport sector under the reference case would consume 74% of the total budget, leaving only 26% for all other sectors such as buildings, food and agriculture, industrial production and all other economic activities.

Under the reference case, OECD North America, OECD Europe and OECD Pacific, with around 15% of the global population, the transport sector would take up 26% of the total carbon budget. Restructuring the transport sector is without alternative. Under the 1.5˚C pathway, the transport sector will have about a quarter (110 Gt) of the total carbon budget (400 Gt) required to achieve the Paris Climate Agreement Goals. Under the 1.5°C scenario OECD North America, OECD Europe and OECD Pacific, would see total emissions add up to 50 Gt CO_2 – around 45% of the remaining carbon budget for the transport sector (110 Gt).

TUMI
Transformative Urban Mobility Initiative

The Transformative Urban Mobility Initiative (TUMI) is the leading global implementation initiative on sustainable mobility, formed through the union of 11 prestigious partners. TUMI's vision are thriving cities with enhanced economic, social and environmental performances in line with the New Urban Agenda, the Agenda 2030 and the Paris Agreement. TUMI is based on three pillars: innovation, knowledge, investment.

TUMI Partners are the Asian Development Bank (ADB), C40 Cities – Climate Leadership Group, Development Bank of Latin America (CAF), Federal Ministry for Economic Cooperation and Development (BMZ), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, ICLEI – Local Governments for Sustainability, Institute for Transportation & Development Policy (ITDP), Kreditanstalt für Wiederaufbau (KFW), SLOCAT Partnership on Sustainable Low Carbon Transport, UN-Habitat, World Resources Institute (WRI). TUMI is implemented by GIZ and funded by the German Federal Ministry for Economic Cooperation and Development (BMZ).


TECH Shuttle
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1. Scope

TUMI's mission is to enable urban leaders, decision-makers, planners and students to plan and implement sustainable mobility concepts with tailor-made capacity-building formats, such as trainings, webinars or training publications and materials.

For the first time in history, more people live in cities than not, and that number is growing rapidly. Cities are directly responsible for around two-thirds of global final energy use as well as for significant indirect consumption of energy through other goods and materials: cities account for around 75% of global CO2 emissions.

Urban dwellers currently account for over half of the global population. With a continued flow of people moving from rural areas to urban and peripheral urban areas, the urban population is expected to grow by 2.5 billion over the next three decades.

Cities as a big energy consumer are at the frontline of the energy transition, therefore strengthening robust policy-making through enhanced science-based road mapping of renewable energy driven scenarios will be key for cities to remain at the forefront of climate action and sustainability. One of the most important sectors in urban development is a shift towards sustainable transport systems.

About the One Earth Climate Model

The One Earth Climate Model developed with the German Aerospace Center (DLR) and University of Melbourne, developing a ground-breaking new framework for achieving the Paris Agreement target of limiting warming to 1.5°C can be achieved by 2050.

It is the first model to achieve the required emissions reduction without relying on expensive or unproven technologies to draw down greenhouse gases out of the atmosphere. Researchers, led by ISF's Dr. Sven Teske, conducted one of the most detailed climate and energy studies to date with 72 regional energy grids in hourly increments through to 2050. The model includes a comprehensive assessment of available renewable resources such as wind and solar, and configurations for meeting projected energy demand and storage most efficiently for all sectors over the next 30 years.

The One Earth Climate consists of a cascade of bottom up energy modelling tools to determine the development of sectorial energy demand developments such as transport, buildings and industry and connects them with each other. The interconnection of all sub-sectors to an overall energy system model enables the calculation of energy supply possibilities with increasing sector coupling. The model can calculate different geoprahical regions individually and bring them together in a further step. This avoids e.g. limited amount for a sustainable bioenergy potential cannot be calculated twice.

1.1. Scope of services

For this project, UTS-ISF provided services according to Terms of reference: Development of global transport scenario in line with the Paris Agreement and Agenda 2030.

Table 2. Work package overview

Work package	Scope and deliverables	
1	For the preparation of the study, first of all existing scenarios for mobility, energy, land consumption, accessibility and spatial structure will be evaluated.	
	• WP1.1 Research of existing scenarios for mobility, energy, land consumption and spatial structure and necessary transformations with time horizons of 2025, 2030 and 2050. • WP1.2 Evaluation of the scenarios with regard to used target values, proposed measures, and parameters used and assumptions made. • WP1.3 Initial evaluation around key parameters and assumptions to be taken into account / to be dismissed (in coordination with contractor)	**Deliverable**: UTS/ISF will analyse a set of scenarios and compare transport related parameters. The data will be delivered in an excel sheet plus a written analysis. Details: Work package 1 & methods.
2	In parallel, different approaches to the attribution of GHG emission rights until 2050 and, based on the chosen approach, the emissions budget intended for the global transport sector will be defined.	
	• WP2.1 Research of existing approaches to the global allocation of GHG emission budgets for compliance with the 1.5°C target. • WP2.2 Decision for an attribution approach and determination of an emission budget for world regions. • WP2.3 Evaluation of scenarios to determine a sub-budget for the emissions of the transport sector.	**Deliverable:** UTS/ISF will analyse the above selected scenarios to determine a global and regional cumulative and annual energy-related carbon budget between 2020 and 2050. The data will be delivered in an excel sheet plus a written analysis. Details: Work package 2 & methods.
3	Based on this, transformation/transition paths to a target scenario based on existing frameworks around the world in the coming 30 years will be developed.	
	• WP.3.1 The framework data to be used is to be agreed with the contractor at the beginning of the project. The scenario researched in WP1 serve as input. Compliance with the GMR and GSR by SUM4All and SLOCAT should be ensured. • WP.3.2 The presentation of an existing data framework and model methodology with input data and output data specification to perform the required forecasting / backcasting calculations. • WP3.3 Depending on the transformation/transition paths the model is determined. The model is being used to determine the energy demand. • WP3.4 The model is coupled with specific modules to include aspects such as spatial resolutions in key regions, freight, mix of technologies, transport models in respect to modal split, aviation, shipping • WP3.5 Based on the tasks in WP3.1-WP3.3 a quantitative framework is being created taking forecasting and backcasting into account.	**Deliverable:** UTS/ISF will develop one global 1.5˚C transport transition scenario which is based on 10 regional (IEA regions) scenarios. The scenarios are based on parameters selected with GIZ - based on results of WP 1& 2. The scenario narrative(s) are discussed with GIZ before UTS/ISF will start computing. The data will be delivered in an excel sheet plus a written analysis. Details: Work package 3 & methods.
4	The central result of the project to be developed will be a scenario for a long-term GHG neutral transport system, in compliance with the 1.5°C target, in 2050.	
	• WP4.1 The scenario will be adapted based on the discussion with the contractor. • WP4.2 The scenario will be finalised.	**Deliverable:** UTS/ISF will complete the transport scenario developed on the basis of the previous 3 work packages. The scenario will be documented in a work document and all data will be delivered in excel sheets. UTS/ISF will prepare a power point for a workshop to discuss draft. Details: Work package 4 & methods.


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2. Analysis of published scenarios

Energy scenarios are an important part of the debate about energy and climate policies. Energy scenario focus on the estimated energy demand and the resulting carbon dioxide emissions. Transport scenarios focus on the actual transport demand of people and/or freight. The difference between the two is the focus of the research and purpose what those scenarios are made for. On a global level, energy-focused transport sector scenarios are clearly dominating. This section aims to explain the differences and presents the key results of selected scenarios.

An introduction to scenarios

Scenarios are "what if" analyses, not forecasts. An energy model – a specific computer tool – uses a set of input parameters and assumptions in order to map out what could happen in the energy sector in response to the implementation of certain policies, or under various different cost scenarios and/or technological developments.

An energy scenario therefore shows what might happen under clearly defined assumptions – it is not a prediction. This is arguably a necessary approach, since making definite forecasts of such complex systems as the global energy market is impossible given that it includes, among many things, assumptions regarding human behaviour and innovation.[1]

Selected scenarios

In this research, we selected the following scenario on the base of:

- Relevance in the political debate
- Relevance in the scientific literature
- Accessibility of data

For the energy scenario category, we analysed the annual International Energy Agencies (IEA) World Energy Outlook (WEO) publications of the past 10 years and the climate and energy scenarios of the International Panel on Climate Change (IPCC). The IPCC scenario database contains over 400 scenarios with various climate targets – from under 2.0°C to over 5.0°C – and therefore significantly different carbon budgets.

2.1. Energy scenario versus mobility scenarios

Energy scenarios are focused on the development of possible energy demand and supply of the entire energy sector. Energy demand and supply is usually broken down by the main sectors such as industry, buildings and transport. The level of detail to which each sector is analysed is significantly different – even within the same scenario. Demand developments are often based on annual changes in demand – or supply – in percent per year. A detailed analysis of the actual transport demand – in regard to travelled kilometers (= passenger kilometer per year) or transported freight (= ton kilometer per year) is often not included.

Mobility scenario focus on actual transport – mobility – demand in regard to passenger kilometers or ton-kilometers per year. Mobility scenarios take more specific regional circumstances into account and are focused on transport demand development of a country, a state or even focused on a specific city. A technology specific supply side – in regard to the required provided energy – in form of electricity and fuels – are not the focus of mobility concepts. In this section, we provide an overview of energy and climate focused scenarios from the International Panel on Climate Change (IPCC) and the International Energy Agency (IEA) first, and mobility focused scenarios afterwards.

2.1.1. IPCC AR 5/6 scenarios

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change (IPCC 2021[2]). The IPCC compiles climate and energy scenarios with a whole range of assumptions which are published in Assessment Reports (AR). During the time of writing (early 2021) the sixth assessment report was in the final stage.

> *'Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land-use patterns, technology and climate policy. The Representative Concentration Pathways, (RCPs) which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land-use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions (‚baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5. RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures. The RCPs are consistent with the wide range of scenarios in the literature as assessed by WGIII Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO2 emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios analysed in WGIII. Any given level of warming is associated with a range of cumulative CO2 emissions, and therefore, e.g., higher emissions in earlier decades imply lower emissions later.'*

IPCC's Fifth Assessment Report (AR5), Summary for Policymakers

The data for the analysis of the published IPCC AR 5 scenarios has been taken from a dedicated website (IIASA 2021[3]).

2.1.2. IEA scenarios

The International Energy Agency (IEA) plays a key role in the world's energy systems debate. Its own description places it "at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations". Its mission is to "shape a secure and sustainable energy future for all".[4]

Since it's founding in 1973 as an agency of the OECD, the IEA has broadened it's activities from its original focus on oil to the entire energy complex and has a role in many critical international climate initiatives. It has been a high-profile advocate for clean energy stimulus measures in response to the COVID pandemic.[5] Leading commentators have suggested it should adopt a formal role as an authority to help manage the international effort to reach net zero carbon emissions.[6]

IEA's World Energy Outload (WEO)

In it's forward-looking analysis, the WEO typically presents three different scenarios, although the names of these have changed over time.

- **Baseline or "business as usual" scenarios: Assuming no change to existing, implemented energy policy**

  It's baseline Current Policies Scenario considers how energy markets would evolve if governments made no changes to existing policies and measures. This used to be known as the Reference Case Scenario.

- **Central scenarios: Assuming that announced policies will be implemented**

  The Stated Policies Scenario, previously known as the New Policies Scenario, considers how current policy ambitions would affect the energy sector: in addition to existing policies, it considers policies that have already been announced but are not yet implemented. In this report, we refer to these as central scenarios.

- **Climate scenarios: Assuming future policies will constrain emissions to meet a specified warming level.**

  The Sustainable Development Scenario maps out how to meet sustainable energy goals in full, aligned with the Paris Agreement and holding the rise in global temperatures to well below 2°C, and meeting objectives relating to universal energy access and cleaner air. Earlier iterations of this scenario include the 450 Scenario and the Alternative Policy Scenario. We refer to these as last as climate (or climate-constrained) scenarios.

The IEA and the IPCC

The IEA WEO plays an important role in the United Nations Framework Convention on Climate Change (UNFCCC) process around the global climate negotiations and supplies data as well as scenarios for possible decarbonisation pathways.[7]

In 1990, the First Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) was published, and a global and national greenhouse gas inventory statistic was established. The IEA has been cooperating with the IPCC since 1991 and, over time, IEA experts have contributed to setting out international methodologies, such as the various editions of the IPCC Guidelines for GHG inventories and have taken part in the GHG review process of the UNFCCC.[8] In December 2017, the IEA and the IPCC held a two-day expert meeting in which both organisations agreed to widen their cooperation and to work together in capacity-building to develop energy-related national statistical systems in developing countries.

Furthermore, the IEA and IPCC want to broaden their work on data, which encompasses contributions on scenario work to the IPCC report on 1.5 degrees as a key input to the Talanoa Dialogue, the collective stock-taking process undertaken in 2018 to assess progress towards the Paris Agreement's long-term goals.[9] The IEA is the "lead custodian agency" for Sustainable Development Goal 7.2 on renewable energy and 7.3 on energy efficiency. It is also a custodian of SDG target 12.c, which aims to rationalise inefficient fossil-fuel subsidies that encourage wasteful consumption.[10]

Since 2001, the IEA has collected and published global energy-related carbon emissions data, a vital data source for the global climate discussion (European Commission and IEA 2017[11]).

Other climate and energy transition initiatives

The IEA is formally involved in other processes and initiatives, such as:

- The Clean Energy Ministerial, a high-level forum hosted by the IEA;
- The Clean Energy Transitions Programme;
- The Electric Vehicle Initiative;
- Energy Efficiency in Emerging Economies;
- EU4Energy;
- The Global Commission for Urgent Action on Energy Efficiency; and
- The Technology Collaboration programme for solar PV, wind and other technologies.

2.1.3. IPCC Scenario Analysis

In this section we provide an overview about the IPCC climate and energy scenarios – focused on the results for the transport sector only. The scenario results for the transport sector are broken down to passenger transport, freight transport and – in a last step - the overall energy demand.

Final Energy Global Passenger transport demand 2030 & 2050

The final energy demand for passenger transport in 2030 and 2050 varies significantly across all analysed scenarios (Figure 2). There are three main categories in those 350 scenarios: 450ppm, 550ppm and base case (or reference). The 450 ppm scenarios represent approximately 2.0°C scenarios (IPCC 2007[12]) , 550 ppm +3°C (IPCC 2007) and the base or reference case is the development based on the assumption that the trends in the past continues. Reference cases change significantly with the changes happened in the energy sector over the past two decades.

The data base does not include any 350ppm scenarios (=1.5°C). However, the upcoming IPCC AR 6 report – publication planned for late 2021 or early 2022 – will include those scenarios.

The global projected energy demand for transport only decreased in some – but not all – 450ppm scenarios. Almost all scenarios project a significant increase of global energy demand for transport between 2020 and 2030 with a further increase towards 2050.

Figure 2. IPCC AR 5 Final energy demand for passenger transport in 2030 and 2050

The lowest transport demand scenario of this data selection is the 'EMF27 LIM Bio'[13] scenario. The EMF 27 scenario series was a joined project of several research organisations under the leadership of the Potsdam Institute and the International Institute for Applied Systems Analysis (IIASA) in 2013/2014. A large number of scenarios under various assumptions was calculated in support of the IPCC AR5. However, detailed documentations for each specific scenario is not available. The indicated scenario with very low energy demand per passenger has a high share of electrified vehicles.

On average, the analysed 350 scenarios estimate an increase of the energy demand for passenger transport of 66% between 2020 and 2050. The lowest estimation reduced the demand by 66% while the most increase demand projection assumed a doubling over the next 30 years.

Passenger Kilometers

The analysis of the underlying passenger kilometers and their projection towards 2050 by region shows significant differences as well. The IPCC database does not include specific kilometer data for each scenario and the size of the sample for each region varies as well. Furthermore, the base year - and therefore the time of publication - for those scenarios varies from 2005 to 2015. While the different base years explain the differences within the estimated development of passenger kilometer for the regions shown in Table 3 to some extent, this research showed that estimations for passenger kilometers varies significantly for historical data series as well. Due to the large variation of passenger kilometers estimated for the base year (2019), a consistent use of one dataset for the regions and globally is required.

Table 3. Estimated passenger kilometers [billion pkm/a] – IPCC AR5/6 database

	2020			2030			2040			2050			Delta 2030-2050		
	min	max	average	min	max	average	min	max	average	min	max	average	min	max	average
	2020 MIN	2020 MAX	2020 AV	2030 MIN	2030 MAX	2030 AV	2040 MIN	2040 MAX	2040 AV	2050 MIN	2050 MAX	2050 AV	DELTA MIN	DELTA MAX	DELTA AV
Asia	8,177	35,569	15,143	10,520	54,452	21,876	13,565	75,077	28,612	17,665	89,933	34,841	4,925	35,481	12,966
LAM	2,640	5,249	3,612	3,557	7,374	4,790	4,602	10,002	6,144	5,626	12,625	7,488	1,450	5,251	2,698
MAF	2,637	8,114	5,686	3,551	12,028	8,098	4,856	17,111	11,374	6,312	26,211	15,580	2,760	16,231	7,482
OECD	9,637	25,474	18,967	10,552	28,104	20,253	11,390	31,148	21,355	10,341	34,133	22,479	-3,796	6,028	2,226
REF	1,983	4,796	3,787	2,049	6,126	4,626	2,346	7,026	5,392	2,604	7,454	5,986	-65	2,907	1,360
World	35,555	69,543	46,141	40,360	97,884	57,486	38,150	129,051	69,530	29,540	156,843	81,827	-13,570	58,959	24,340

LAM: Latin America; MAF: Middle East and Africa, REF: Russia and the former USSR

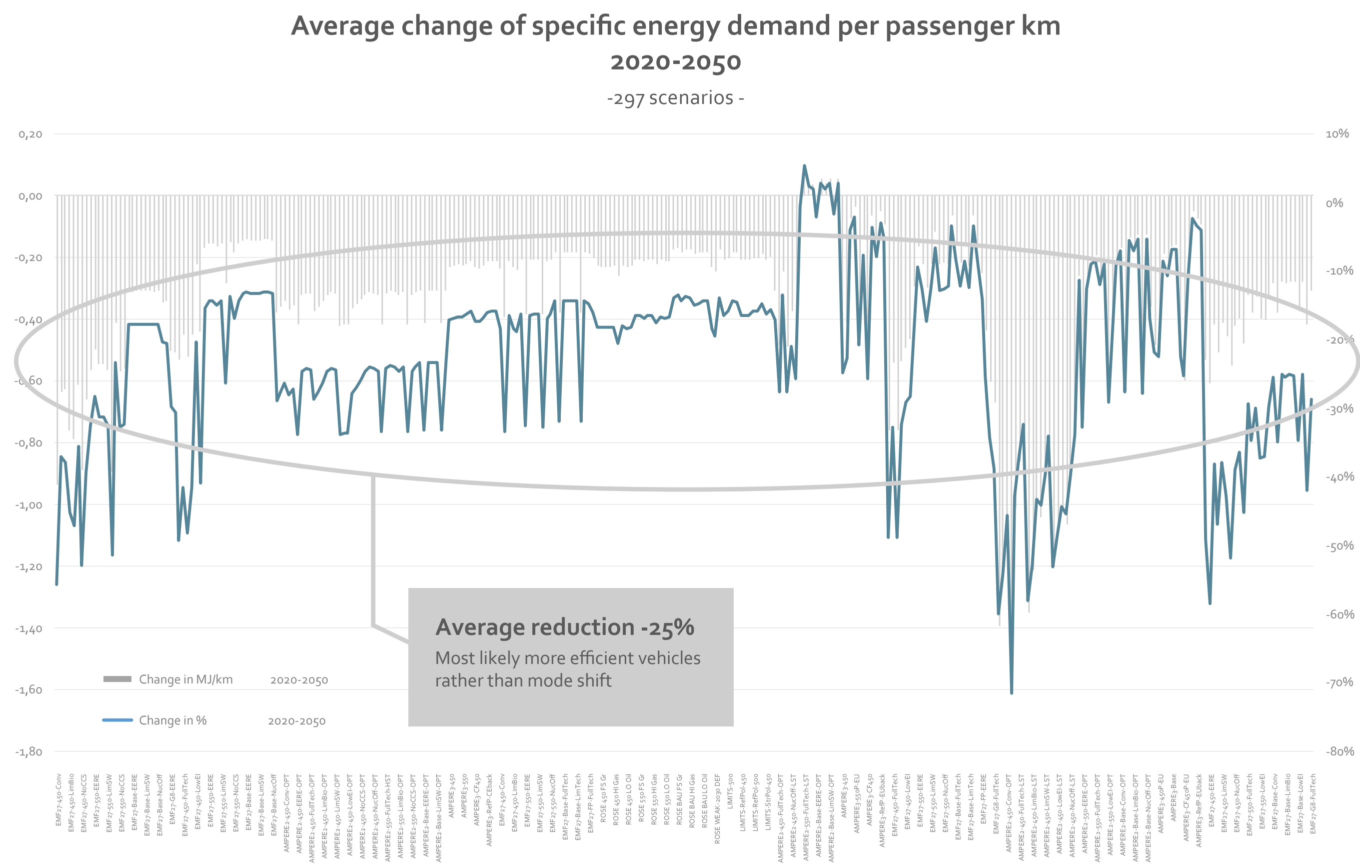


Figure 3. Average change of specific energy demand per passenger kilometre

IPCC Scenario – Passenger Kilometer: Average change of specific energy demand per passenger kilometer

Based on published energy demand and passenger kilometer for each scenario, the specific energy demand per passenger kilometer for each scenario has been calculated individually to compare the estimated changes for each scenario. Figure 3 (see page 28) shows the average change of specific energy use over time between 2020 and 2050. The energy intensity has been calculated as an average for passenger transport. A further breakdown by vehicle type requires the respective regional market shares which were not available.

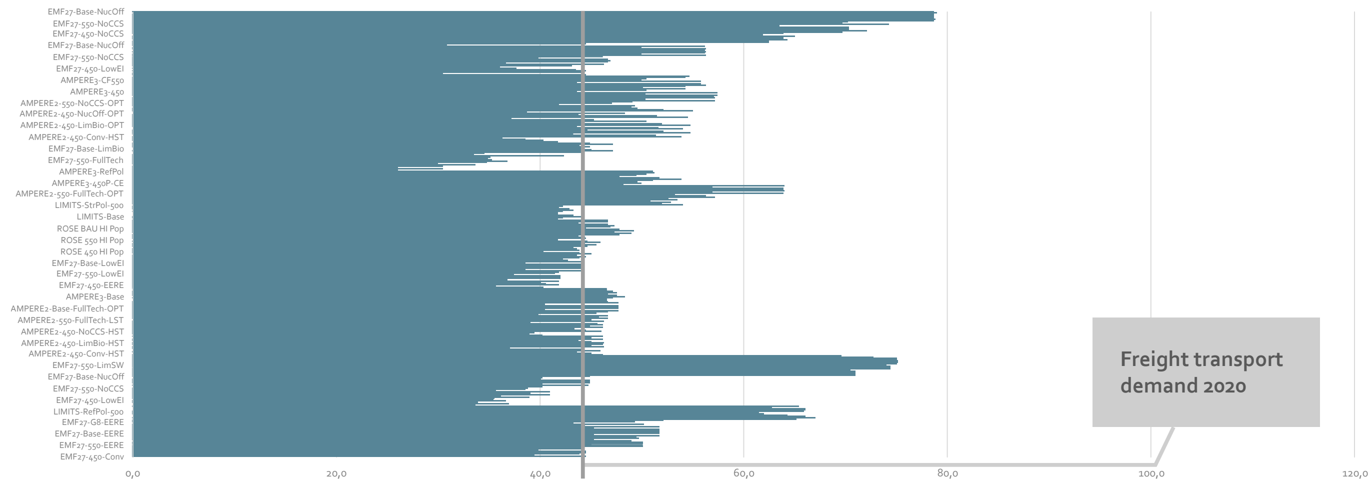
On average across 297 scenarios, the energy intensity per passenger kilometer is projected to decrease from 1.2 MJ/pkm to 0.85 MJ/pkm – 23% - between 2020 and 2050. For comparison: the average energy intensity of a medium sized car with internal combustion engine is currently at 1.4 MJ/pkm and an electric vehicle of a similar size achieves 0.5 MJ/pkm.

Final Energy Global Freight transport demand 2030 & 2050

The projection for the final energy demand of freight transport in 2030 and 2050 is equally volatile as for passenger transport (Figure 4). Again, there are three main categories for the analysed scenarios: 450ppm, 550ppm and base case (or reference).

The lowest transport demand scenario of this data selection is the 'AMPERE2-450-EERE-OPT'[14] scenario and has been calculated by IIASA with a MESSAGE (version 2) – a model which has been used to calculate scenarios for the IPCC AR5. Just as EMF 27 scenario, MESSAGE scenarios calculated IPCC scenarios in huge numbers with various assumptions, but specific documentation of all input assumptions for specific scenarios is not available.

IPCC AR5 Transport Scenarios: Final Energy Freight Transport Demand in [Ej/a] for 2030



IPCC AR5 Transport Scenarios: Final Energy Freight Transport Demand in [Ej/a] for 2050

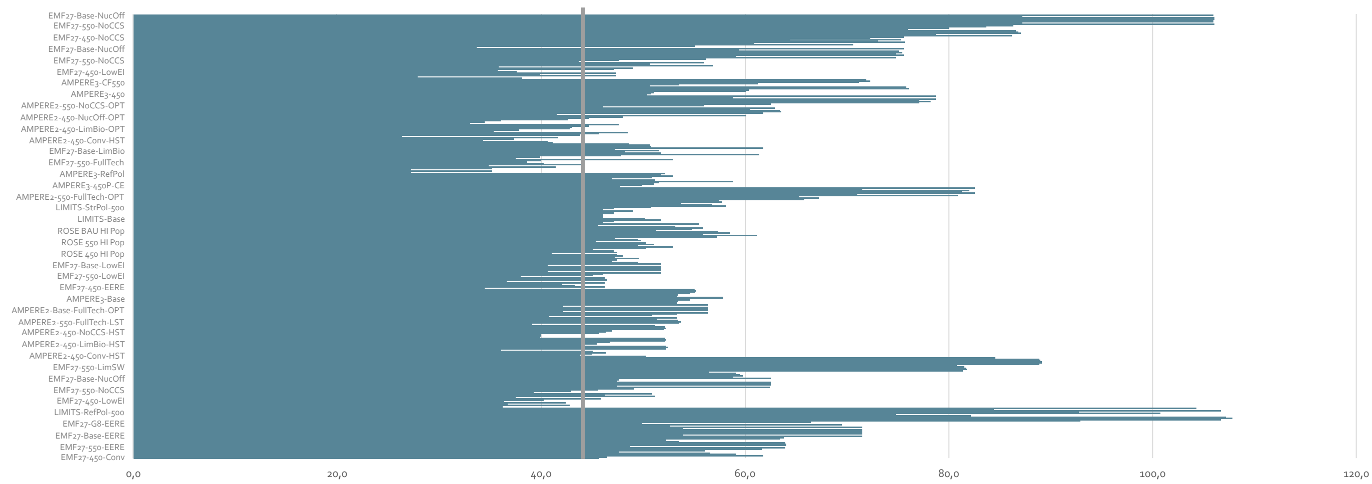


Figure 4. IPCC AR 5 Final energy demand for freight transport in 2030 and 2050

The 450 EERE-OPT scenarios do not include Carbon Capture and Storage (CCS)[15] and focusses on energy efficiency and renewable energy use. On average, the analysed 352 scenarios estimate an increase of energy demand for freight transport of 35% between 2020 and 2050, with a variation between -37% and plus 157%. Figure 5 shows the variation by scenario. The overall majority of energy scenarios project a substantial increase of energy demand for freight.

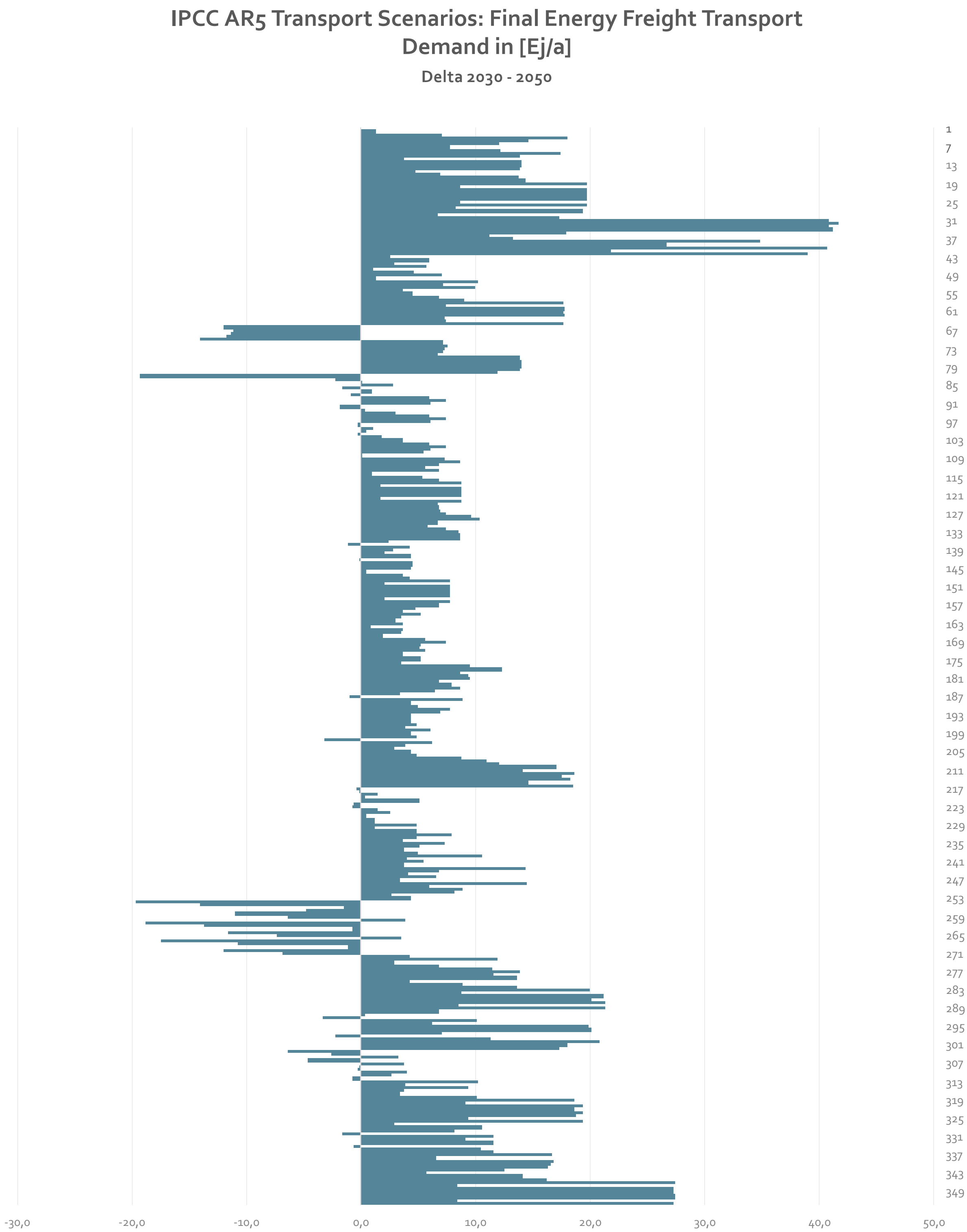
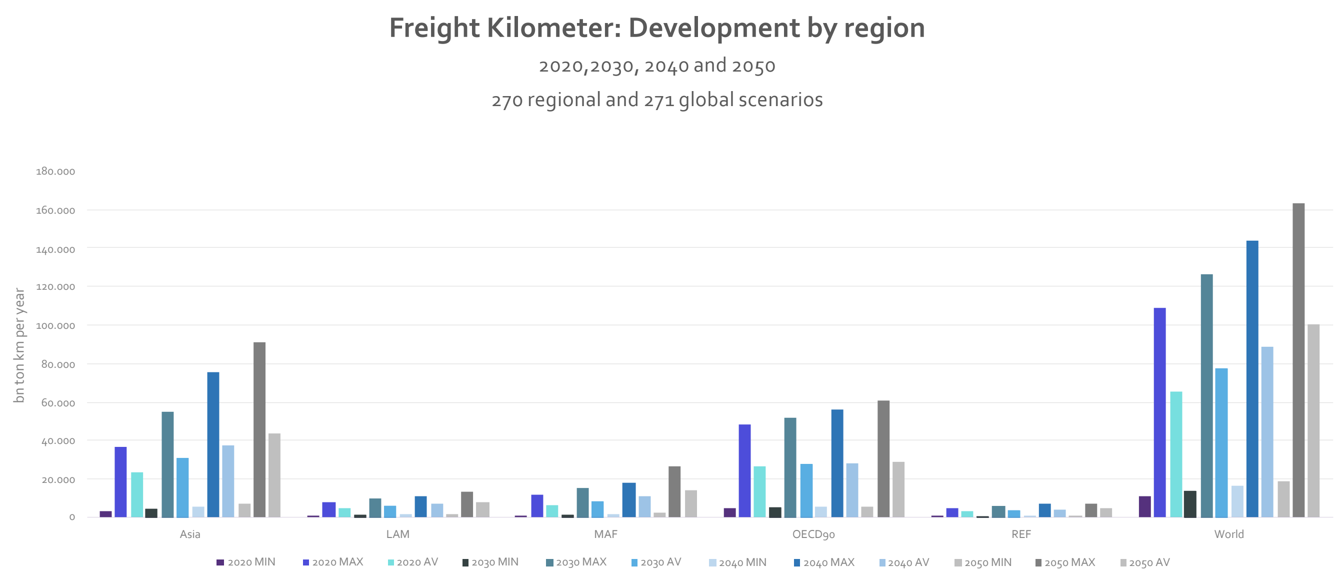


Figure 5. Freight transport demand – variation of analysed scenarios



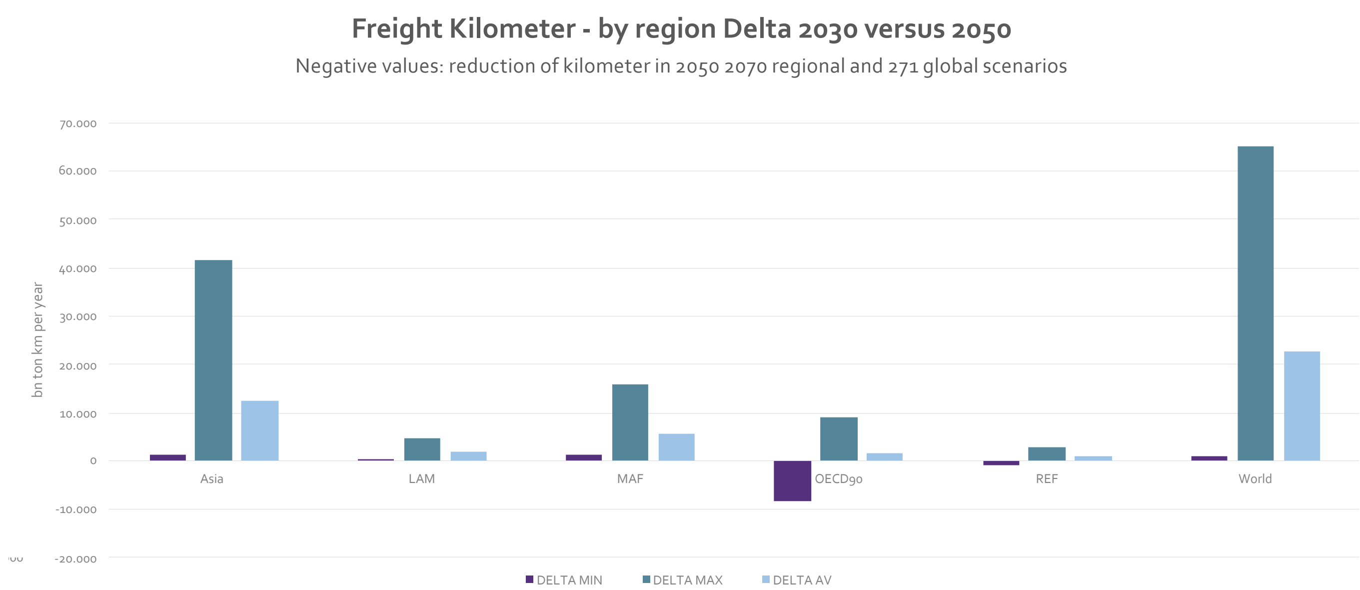


Figure 6. Freight Kilometre – Development and variation by region

Development of freight demand in ton-kilometer

An analysis of the available regional IPCC scenarios shows in Figure 6, that the overall energy demand – as well as the volume of freight in ton-kilometer – is expected to increase mainly in developing countries and in Asia, namely China and India. Again, the spread in-between different estimations vary by scenario significantly.

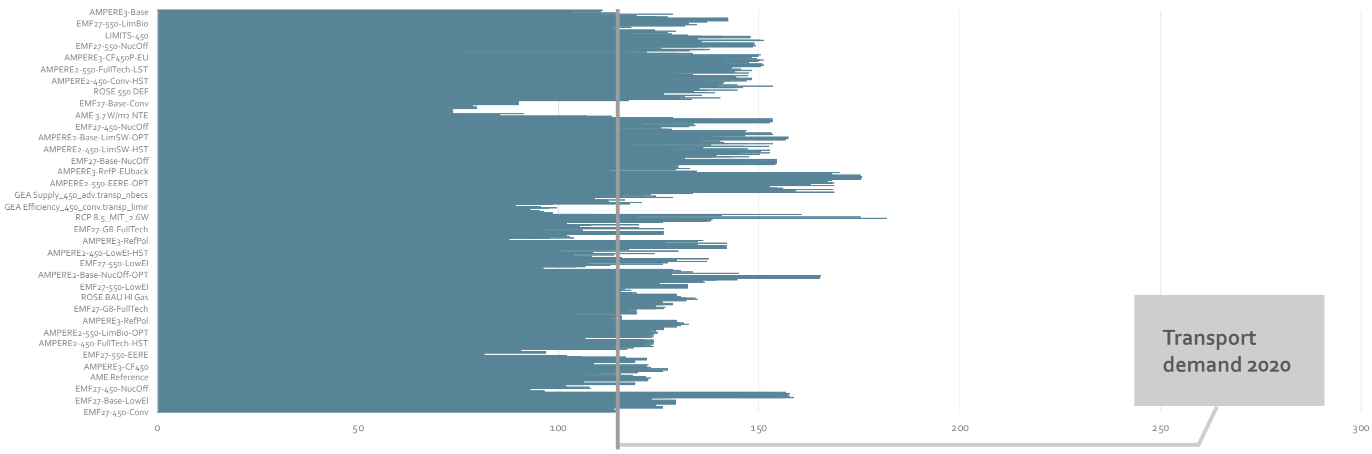
The trend, however, is the same in all scenarios: Developing countries will significantly increase freight transport volumes while the OECD countries will remain on a high level with only minor increase over the next 30 years.

Global final energy demand for transport – projection for 2030 & 2050

Specific data for passenger and freight transport demand wasn't available for all scenarios of the IPCC AR5 database. Furthermore, a regional breakdown of the global energy demand for transport by scenario was not available for a large share of the analysed scenarios. In addition, the regional breakdown varies so that a comparison would not have been possible. The analysis of energy demand projections for the global transport sector between 2020 and 2050 includes 810 scenarios (Figure 7). In comparison to the passenger and freight transport scenario, the trend of the overall transport energy demand over the next 30 years is towards reduction. While the IPCC scenarios do not provide the full set of assumptions, the increased demand for electricity in the freight transport sector indicates electrification is the main reason for the reduction of final energy.

The majority of 450ppm scenarios estimate a slight demand increase with a peak between 2030 and 2035 and a reduction afterwards. To conclude: IPCC scenarios with a target of a temperature rise of around +2.0°C see the need for a reduction of energy demand in the transport sector in order to remain within the carbon budget.

IPCC AR5 Transport Scenarios: World - Final Energy Transport Demand in [EJ/a] for 2030



IPCC AR5 Transport Scenarios: World - Final Energy Transport Demand in [EJ/a] for 2050

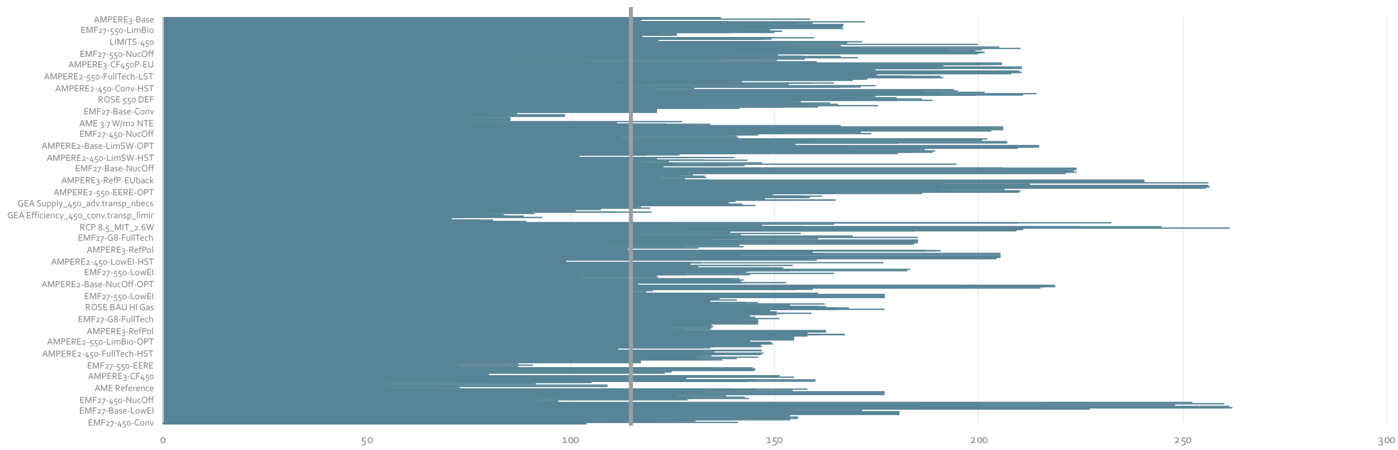


Figure 7. Global final energy demand for transport – projection for 2030 and 2050

2.2. Supply: IEA Projection of oil demand for transport

According to the IEA World Energy Outlook 2020, oil supplies 91% of all transport energy needs. Combustion engines in planes, ships, trucks, busses and passenger vehicles represent the dominating technology. Therefore, this section focusses on demand project for oil in the transport sector. A reduction of the projected oil demand indicates than one or more of the following measures are assumed:

- Increase of motor and vehicle efficiency
- Switch to other fuels such as gas, synthetic fuels, hydrogen or biofuels
- Increased use of electric drives
- Decrease of overall transport demand for passengers and/or freight
- Increase of alternative transport modes such as bicycles and/or walking

Figure 8 shows the projections of the IEA for oil demand in the transport sector in three main scenarios – New policy (NP), current policy (CP) and 450ppm (Sustainable Development – SD), published in IEA's annual World Energy Outlook between 2010 and 2019 and the actual development between 2008 and 2017.

The comparison of actual development with IEA projections shows that all scenarios which projected a stagnation or reduction of energy demand did not materialize. Instead, the overall demand for oil in the transport sector continues to rise. On average between 3% and 2% per year. Thus the trend in oil consumption is still towards growth and has not reached a peak.

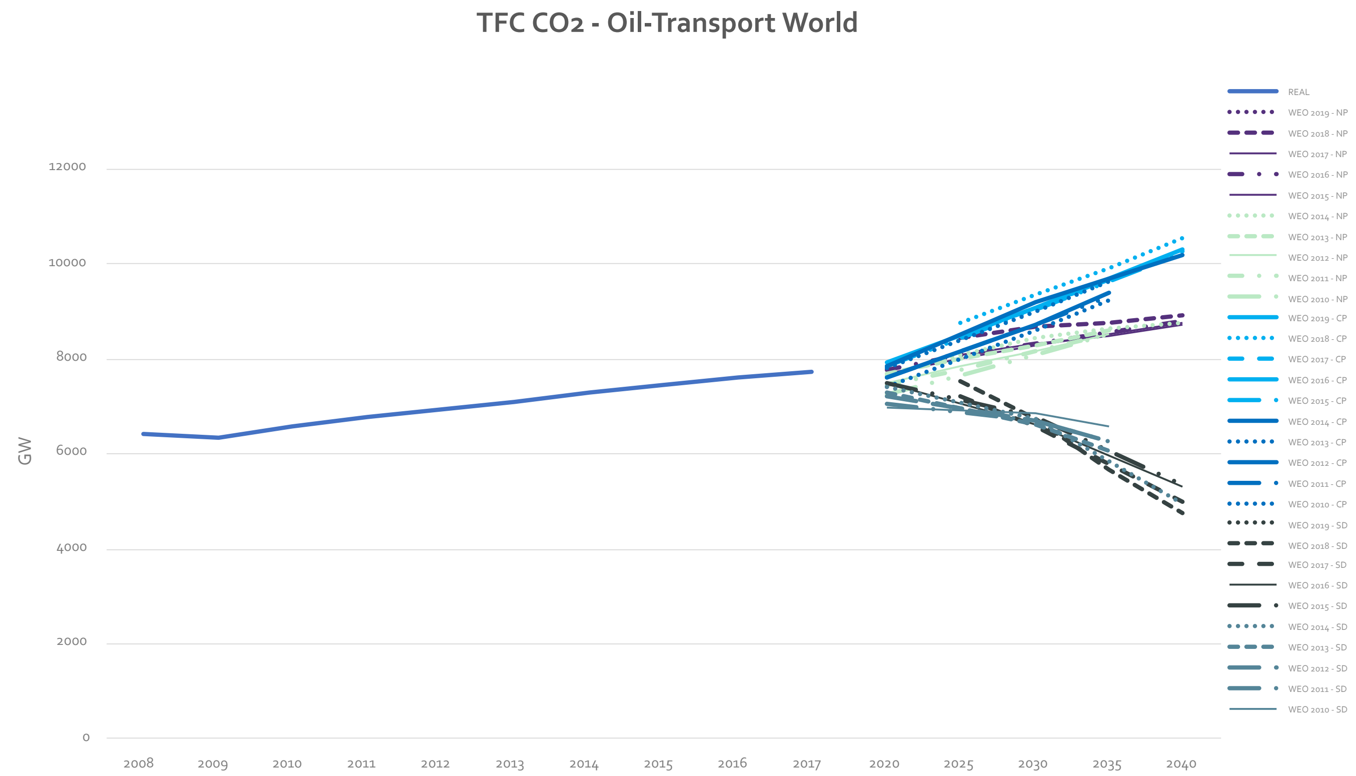


Figure 8. IEA WEO - Total Final Energy Consumption (TFC) for oil in the transport sector under various projections

2.3. Mobility scenarios

The following scenarios are examples of mobility scenarios. In comparison to the energy and climate scenarios, the focus is more on the actual transport demand and specific measures to reduce transport demand.

2.3.1. Mobility Scenario 1

A Global High Shift Scenario: Impacts and Potential for More Public Transport, Walking and Cycling with Lower Car Use (2014), Institute for Transportation and Development Policy (ITDP), University of California, Davis

Overview

This global transport study focuses on urban centres, which are expected to grow until 2050. This study compares the IEA 2012 Mobility Model (MoMo) 4°Scenario with a High-shift scenario which sees a major shift from private vehicles towards clean public transport (powered by renewables electricity) and a shift towards low-power transport modes, which include e-mobility scooters and e-bikes as well as non-motorised transport (NMT) options, i.e., walking and cycling. The study focuses on five major markets: US, Europe, China, India and Brazil. Non-OECD countries characterised by large populations and high population densities have different priorities and require different modes shift compared to developed countries. But also among developed countries the scenario makes stark distinctions between the US and Europe.

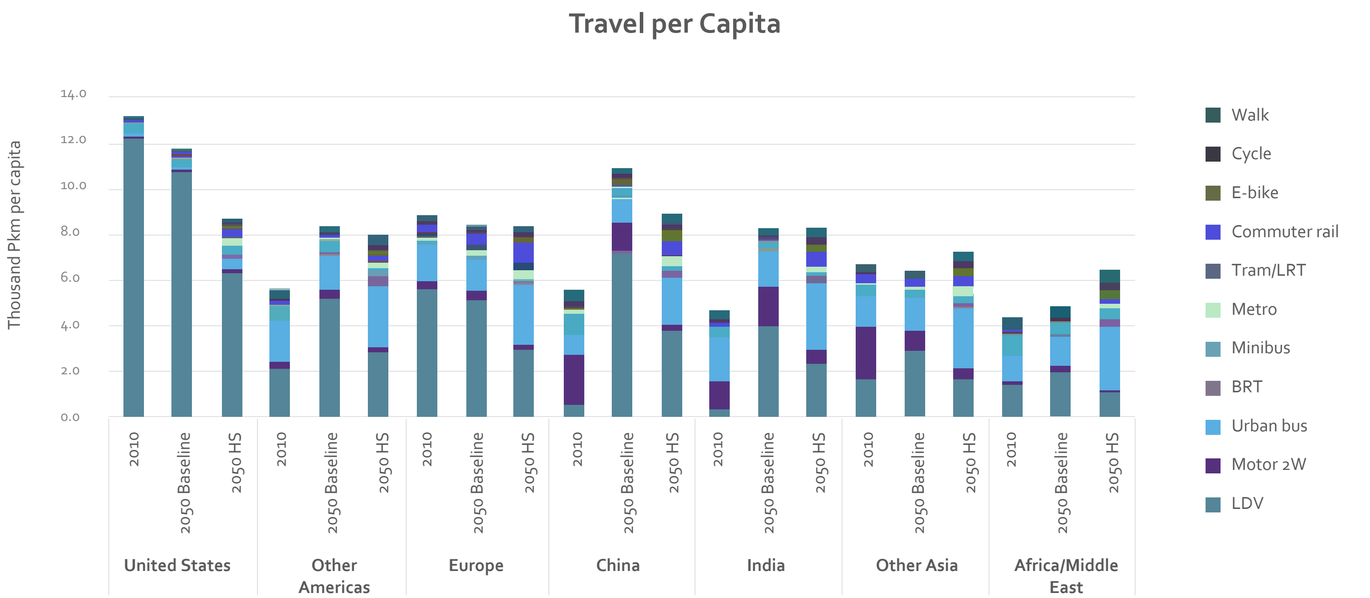
Methodology

Baseline scenario: ITDP's Global High Shift Scenario uses the IEA ETP 2012 MoMo 4°C global warming scenario as a baseline. IEA MoMo is a transport scenario that has been developed for analysis at the national level and focuses on energy use and resulting CO2 emissions. Since this study focuses on urban travel and development of mode share in the urban environment have been elaborated from the MoMo framework. This scenario assumes a global climate agreement including the implementation of a carbon pricing system to reduce GHG emissions, but not taking into consideration sectorial pathways or targets (capital investments). Car ownership and the uptake of two-wheelers (continue to) increase while bus and other urban public transport as well as NMT show slow or no growth. As a result, fossil fuels will continue to dominate the transport sector by 2050.

High shift scenario: In this scenario, urban growth is assumed to rise to 66% based on UN projections, i.e. a 16% increase compared to 2014, the year the study was published. To support the increase of public transport options, including rapid transit buses, and NMT, infrastructural chance will take place e.g. in form of constructing (more) bus lanes and cycle paths. The scenario assumes the use of light-duty vehicles (LDV) will half by 2050. This major reduction (-50%) will be achieved by reducing car ownership and an increase in car occupancy. In North America and other OECD countries, infrastructural modification of cities will reduce travel times (trip lengths) thus reduce overall travel. In developing countries, reducing car ownership becomes a challenge if wealth/income increases, economic incentives are needed. The increase of public transport worldwide is based on existing best practise and high-performance travel systems in OECD countries.

Main findings

Countries with the highest GHG emissions such as the USA are dominated by private vehicle transport, while the overall pkm are reduced, the share of LDVs remains high (Figure 9). In the 2050 baseline scenario, the use of LDVs in China is high, but can be reduced by diversifying transport options, increasing LDV occupancy and increasing the shift towards urban buses and rail (high shift). This study considers the shift towards bus rapid transit (BRT) or urban busses a likely option. In the high shift scenario, the use of BRT increases up to 129% in the OECD Pacific region, here the baseline for bus travel is already high, and in North America where initial levels are very low, rapid bus transit increases by 445% in the high shift scenario. Vehicle passenger kilometers drops (vpk) due to increased occupancy rate in 2-3 wheelers and LDVs.



LDV= light-duty vehicles (private cars)

Figure 9. Travel per capita for selected countries/regions

Table 4. Passenger & Freight kilometers

	Urban Bus Rapid Transit BRT /BRT feeder bus*		Metro		Rail	
	2014	2050	2014	2050	2014	2050
Passenger: Person kilometers per lane-km	12-14 million	30-35 million	25-35 million	40-42 million		
Passenger: Person kilometers per year [pkm/a]		16 trillion pkm				2.5 trillion pkm
Freight: ton kilometer per year [tkm/a]	NA	NA	NA	NA	NA	NA

*BRT feeder bus: 1-seat easy transfer rides

Table 5. Mode shift from mode 2015 to mode 2050, by transport mode focused on in USBC studies

	Study 1					Study 2		
From mode	To mode by 2050	Vehicle occupancy in 2-3 wheelers/LDV in 2050 (vs. 2014)				To mode by 2050	Reduction in motorized vehicles	
		Non-OECD	OECD	Non-OECD	OECD		Non-OECD	OECD
LDV	BRT	1.7 (+0.1)	1.6 (+0.2)	-23% per km (baseline scenario)	-32% per km (baseline scenario)	Cycling / e-bike	21% by 2030 (study1)	-18% by 2030 (study1)
				-27% per km (high shift)	36 per km (high shift)		29% by 2030 (study2)	-24% by 2030 (study2)
Motorized 2-3 wheelers	BRT					Cycling / e-bike		
Mini & regular buses	BRT					Cycling / e-bike		
BRT: bus rapid transit						Remain the same		
Minibus						Cycling / e-bike		
Metro car								
Tram/LRT								
Commuter rail								

**50% reduction in fuel use per KM is required for LDV

Energy fuel intensity

- Baseline scenario: 32% less energy intensive (OECD) and 23% less in non-OECD
- High shift scenario: 36% less energy intensive (OECD) and 27% less in non-OECD**

CO2 emissions

- Under the high shift scenario, global urban passenger land transport CO_2 emission will be cut by 1.7GT by 2050, a 40% reduction, from 4.4GT in 2014 to 2.7GT CO_2 by 2050.
- Specific fuel types are not shown but road modes are dominated by petroleum fuel while rail modes are almost entirely electrified, as are e-bikes.
- Overall: Improved public transport, NMT modes (walking, cycling) have the potential to cut CO_2 emissions from annual urban passenger transport in 2050 by 55% from the BAU/baseline scenario by 2050, that's 10% less than 2010 levels.

2.3.2. Mobility Scenario 2

"A Global High Shift Cycling Scenario" (2015). Institute for Transportation and Development Policy (ITDP), University of California, Davis

Overview

This study focuses on cycling (bicycle, e-bike) worldwide, the uptake of cycling as a non-motorised transport mode is of particular relevance for achieving a mode shift in for urban transport. The overall benefits of cycling are manifold, the shift not only eliminates carbon emissions, but it also has economic and health benefits.

Bike share, including e-bikes, have changed urban cycling by a large extent as it increased accessibility (bike, infrastructure) and it's fit-for-purpose; by using smart technology (mobile phone apps) to unlock/lock, bike share allows to cover short trips. Thus, bike share connects with urban public transport through transit bike stations. Due to the low costs and accessibility, governments worldwide have been subsiding bike share systems.

Methodology

BAU Baseline scenario: This study solely focuses on "utility trips" and does not include recreational cycling (trips). Traditionally, quantitative data on has been difficult to obtain. Data collection on frequency and trip length has emerged with bike share and the internet of things. Cycling data for rental bikes is now available. The sale of e-bikes has increased steadily.

In the BAU scenario, urban cycling increases until 2030 and then plateaus. The uptake of cycling in OECD countries (Europe, Japan) is growing but at a low rate of +0.2% annually. In the US, the trend towards cycling increases, but the baseline is comparably much lower. In non-OECD countries, the trend towards cycling decreases (-0.2% annually), instead there's a shift towards LDVs. Politically, e-bike sales were favoured by bans of ICE two-wheelers in Chinese cities to reduce air pollution.

BAU projection for e-bikes looks slightly different as their purpose is primarily for transportation/commuting vs. recreational cycling. E-bike sales increase by 5% annually between 2015 to 2030, and 2.5% from 2030 to 2050 (as sales have been capped). Western Europe follows China in e-bike sales, adoption is similar to the uptake of traditional bikes. For the ROW (excluding China and Western Europe), e-bike sales are slow (but growing for North and Latin America and Africa).

The travelled distance (pkm/day) of a sold/rented e-bike is 6km/day, which corresponds to average LDV travel at the time the study was documented. It is assumed that the daily travelled distance of e-bikes continues to increase until 2050 in countries with existing cycling infrastructure including China (1.8km), Netherlands (1.4km), Japan (1.3km), Denmark (0.9km) and Germany (0.6km) by 2050.

This development is supported by decreasing car dependency and ownership in OECD countries and transitioning of road infrastructure towards cycling lanes. Non-OECD countries focus on car traffic and will not invest in cycling infrastructure.

The high shift scenario compares IMF (2014) data that averages the length of car trips in OECD countries with the average trip length using e-bikes. In Denmark 70% of all car trips are 5 km and in the US 80% of car trips are 8km in length, hence these trips are "cyclable", as mentioned earlier travelled distance (pkm/day) of a sold/rented e-bike is 6km/day. The high shift scenario assumes a broad shift from motorised transport modes towards cycling. Table 5, see column on Reduction in motorised vehicles, shows how the mode shifts takes place.

Main findings

The cost comparison between different motorised transport modes and bike share/purchase show how the increased uptake of riding bicycles can reduce expenses for governments and individuals as costs related to cycling are very small to non-existing with regard to purchase, operation and maintenance (regular checks, insurance, repair), construction of infrastructure (including car parks) and fuel.

In the high shift cycling scenario, the reduction of construction expenses alone, are expected to amount to US$300 billion in 2030. While the 2014 study, estimated US$200 billion savings in energy costs (largely petroleum use), the cycling high shift scenario considers new cycling infrastructure as well as maintenance, combined cost savings are close to US$1 trillion in 2030.

The high shift towards cycling and e-biking reduces additional emissions by 10% percent on top of emission cut in study 1. Estimated monetary savings are US$700 billion annually and add up to US$25 trillion savings between 2015 to 2050.

Total costs by scenario, 2030 and 2050

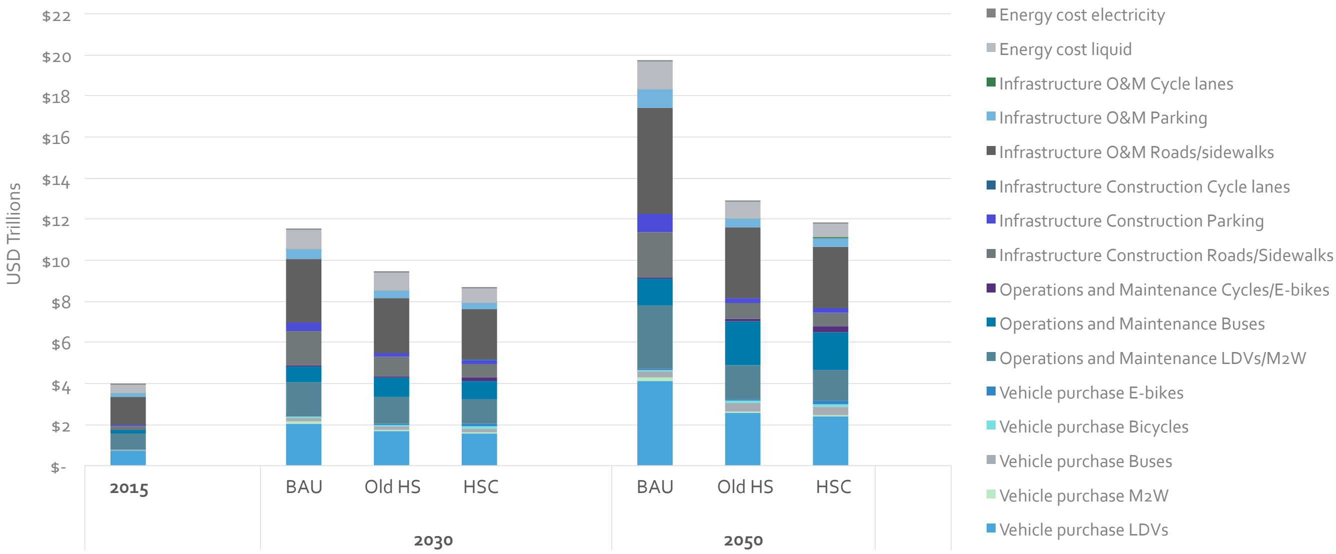


Figure 10. Total costs across all categories by scenario, 2030 and 2050

2.3.3. Mobility Scenario 3

Three Revolutions in Urban Transportation. How to achieve the full potential of vehicle electrification, automation and shared mobility in urban transportation systems around the world by 2050 (2017), Institute for Transportation and Development Policy (ITDP), University of California, Davis

Overview

This study brings together findings from case study 1 and 2 which have focused on non-motorised transport (NMT) modes including walking, cycling and lower car use, and the shift to bicycle and e-bikes, in addition the study considers an increase in vehicle electrification (EVs), vehicle automation (AVs) and a trend towards ride share to improve the urban transport system.

Methodology

The study develops three scenarios, 1 Business as usual (BAU), 2 Revolutions (2R) scenario and 3 Revolutions (3R) scenario.

1 Business as usual (BAU) scenario: Assumptions: No major changes occur between 2017 to 2050, ICE and LDVs continue to dominate until 2050. These assumptions are developed alongside continuous global population growth.

2 Revolutions (2R) scenario: Assumptions: This scenario is based on decarbonisation of the transport sector and focuses on technological fixes, such as electrification of vehicles (increasing share by 2025) followed by automation (automated EV's from 2030 onwards). Private transport modes, in form of EVs and AV, dominate urban transport by 2050.

3 Revolutions (3R) scenario: Assumptions: This scenario combines the previous assumptions laid out in the 2R scenario and expectations that ride share and increased public transport (different-sized buses, rail) and non-motorised modes (cycling, walking) will contribute to a three-dimensional revolution (3R) of the transport sector.

Main findings

The 2R scenario performs well in terms of GHG emissions and is compatible with limiting global warming to 2°C or below. This outcome requires decarbonised electricity sources to power EVs. EV uptake is considered to be slowed down by high purchasing costs for the next decade from the time the study was published in 2017. The contribution of AVs in shaping the future transportation system is uncertain. Although AVs reduce overall transport-related emissions due to electrification, optimise energy consumption and avoid congestion, AVs are expected to increase the number of car trips by 15-20% compared to BAU. A shift to AVs will also reduce the future workforce in the transportation sector, which has pros and cons.

Not surprisingly, the 3 Revolutions (3R) scenario performs best in terms of reducing car dependency and resource consumption. In the scenario, energy use from urban transport is reduced by 70% globally, GHG emissions are reduced by more than 80%, and transport costs (operational, infrastructure, economic) are cut by 40%, i.e. US$5 trillion annually.

Ride share must be "pooled" in order to reduce emissions. Thus, vehicle occupancy must be increased per ride (one ride can consist out of several passenger trips) at a rate of 30-40% compared to BAU by 2050.

COVID-19 impact: It is important to note that throughout 2020 and in many regions 2021, ride share companies have opted out of the pooling option due to hygiene.

There are a number of additional benefits that emerge in the 3R scenario, which require quantification and are subject to further research, including aspects such as reduced travel demand due to increased interconnectivity of transport (e.g. e-bike transit station), greater diversity of transport modes to choose from, more transport modes that are "fit-for-purpose", increased occupancy of vehicles (load factor), fewer infrastructure requirements (parking).

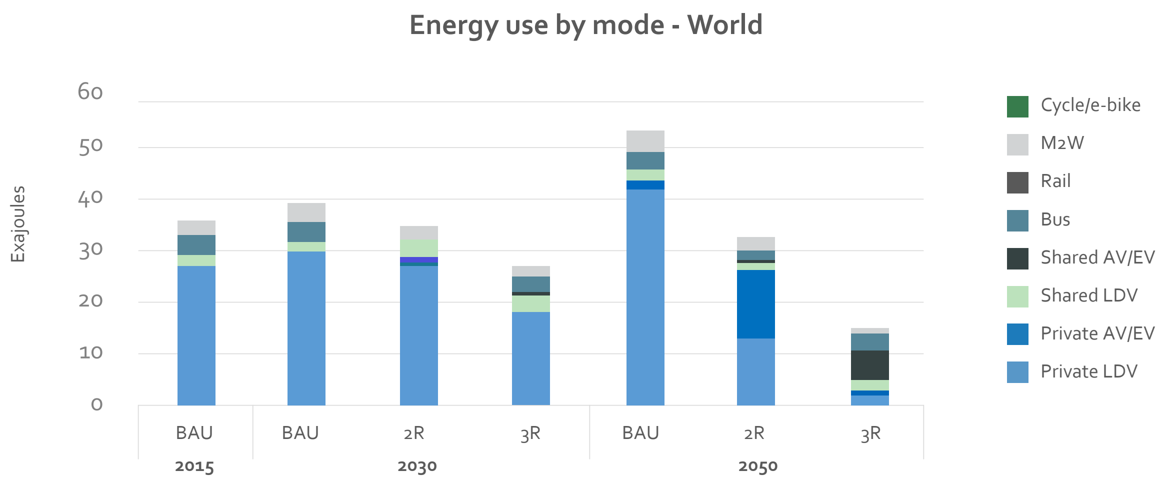


Figure 11. World energy use across all modes, by scenario and year

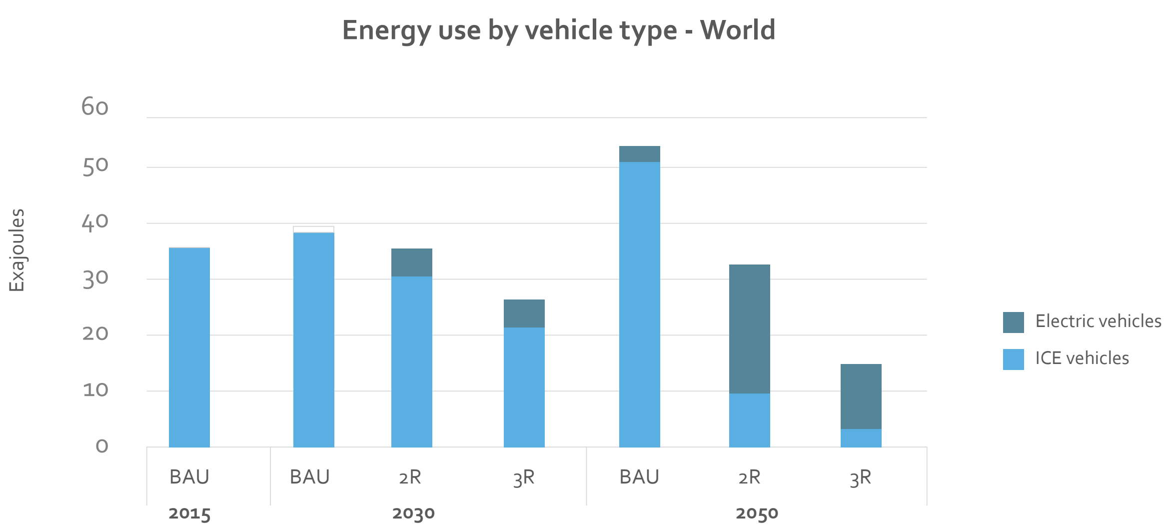


Figure 12. World energy use, ICE vs. EV, by scenario and year

Table 6. World energy use, ICE vs. EV, by scenario and year [exajoules]

	BAU (2015)	Scenarios for 2030			Scenarios for 2050		
	2010	BAU	2R	3R	BAU	2R	3R
ICE vehicles	36	39	31	22	51	10	3
EVs	0	1	5	6	2	22	13
Sum	36	40	36	28	53	32	16

2.3.4. Mobility Scenario 4

Verkehrswende für Deutschland der Weg zu CO2-freier Mobilität bis 2035 (Transition of the transport sector in Germany – A net zero CO2 mobility pathway until 2035)[16]

Background

The transport sector is responsible for 18% of national GHG emissions and 64% of N2 emissions in urban regions are transport-related emissions. The study also points to the major delay in adopting innovative pathways focused on electric vehicles in the German automobile manufacturing industry, which has - instead - been clinging on to internal combustion engines (ICE). As a result, China, facing little competition, has established a leading role in EV manufacturing over the past decade. The transition of the manufacturing sector towards EVs will create future employment in the sector. The timeline to phase out ICE by 2035 is short, and therefore requires the federal government to legislate an end to vehicle registrations for ICE cars.

Public transport modes (train, bus), non-motorised transport modes and sharing infrastructure (ebike, bicycle, car share) are well-established in urban areas in Germany and have not been used sufficiently to reach their full potential. In rural areas, communities are more car-dependent, here the shift will be driven by decarbonising private vehicles. Freight transport will be shifted from road to rail. Electric heavy vehicles are powered by overhead lines on roads and highways, similar to electric buses and trams. In cases where the electrification of heavy vehicles is challenging, fossil fuels are replaced by synthetic fuels (e.g. hydrogen).

Regulatory and policy requirements

- Legal phase-out of ICEs by 2025 will provide an incentive for the manufacturing industry to shift production towards EVs and join/challenge established producers at the global EV market

- Acceleration of the decarbonisation of the energy sector in form of renewable energy infrastructure which must support the electrification of and shifting within transport modes

- Policies to increase the shift towards non-motorised transport modes (cycling, public transport including bus and rail) in Germany

Aims

To contribute to the mitigation of carbon emissions, the study aims to eliminate GHG emissions from 166 million tonnes CO2 in 2016 to zero in 2035, in order to keep global warming below 1.5°C by 2050 according to the Paris agreement.

Reducing passenger transport by 25% over two decades (from 1,172 billion pkm in 2008 to 894 billion pkm in 2035). The growth rate of freight transport will be limited to 9% until 2035 (base is 631 tkm in 2015 to 711 billion tkm in 2035).

The main themes of the transport sector transition:

1. Digitalisation and merger of transport modes including ride shares
2. Governance and regulation of LDVs
3. Vehicle (energy) efficiency, engines, fuel types
4. Decarbonising freight transport

Assumptions for 2035

- Creation of low traffic urban areas: Land use for transport has been reduced by condensing urban transport infrastructure, travelled distances are reduced. No further land use for transport infrastructure.

- Improving public and NMT modes: Urban private passenger transport (LDVs) will be reduced by 2035. The study assumes an ownership rate of 200 LDVs per 1000 residents at the national level and the median distance per LDV will decrease to 13.900 km annually, in urban areas the median rate of motorisation is 154, and is reduced by quarter compared to the national average. Private car use accounts for 34% of travelled distances in 2035, and almost halved from 2008 (58%). The assumption is supported by shifting private transport modes towards cycling and walking. Public transport and cycling will provide for 19% of transport modes and private vehicles for 33% in terms of km travelled.

- Digitalisation and merger of transport modes including ride shares: Ride sharing will increase in urban and rural areas
- Governance and regulation of LDVs: the private vehicle fleet will be reduced to 43%
- Vehicle (energy) efficiency, engines, fuel types: 98% of the private LDV fleet and 80% of HDVs will be electrified, the remaining 20% will use synthetic fuels
- Decarbonising freight transport: 46% of freight transport is moved from road to rail or water ways
- Stark reduction of urban air pollution
- Domestic flights are replaced by high-speed rail

Transport model input variables

- The energy model has been combined with transport parameters to develop a scenario for future passenger travel [pkm/year], here a bottom-up approach has been applied.
- To estimate the shares of future passenger travel, the model incorporates private vehicle data by user groups (age, region, purpose, choice of transport mode, LDV ownership) and by vehicle registration. These categories support their effort to make assumptions about users' likelihood to shift to other transport modes.
- The model will also incorporate a technology mix to demonstrate technology adoption and developments.
- The underlying data for the transport model is a study prepared by Infas/ DLR (2010) for the Federal Ministry of Transport. For the base year 2015, data on population settlement and urbanisation have been updated.

Outcomes

By 2035, energy demand has increased driven by the electrification of the transport sector including the use of batteries and the production of energy intensive fuel alternatives.

In 2035 public transport and NMT increases, especially cycling, private vehicle use decreases including ride shares but private vehicle use drops from 55% to 36% in total. More substantial changes in transport mode shifts especially a reduction in the use of LDVs occur in urban areas (Table 7).

Table 7. Energy demand by 2035

	Passenger Transport (TWh)	Freight Transport (TWh)
Energy storage in form of batteries, incl. losses	55.5	10.0
Energy consumption for transport/mobility	22.3	37.5
Energy consumption for the production and compression of H_2	30.2	9.1
Energy consumption used for the production of synthetic fuels, incl. Syn-hydrogen	0.6	-
Energy consumption used for the production of synthetic fuels incl. Syn-diesel	-	50.6
Direct air capturing (CO_2)	-	1.9
Energy consumption for the hydrogen shift reaction ($CO + H_2O \rightleftharpoons CO_2 + H$)	-	17.3
Total (TWh)	108.6	126.4

Table 8. Transport volume by 2035

	2015 (billion pkm/year)	2015 in %	2035 (billion pkm/year)	2015 in %	Trend
Walking	34	3%	36	4%	Slight increase
Cycling	33	3%	69	8%	Almost 200% increase
LDV (shared)	281	24%	143	16%	Decrease
LDV (private)	643	55%	320	36%	Decrease
Public transport	182	15%	327	37%	More than doubled

Table 9. Transport volume by mode share per regional area (2035)

	2015 (MiD 2008)	2035 Total	2035 Urban areas	2035 Urbanising areas	2035 Regional areas
Walking	24%	28%	29%	27%	28%
Cycling	10%	19%	20%	17%	18%
LDV (shared)	15%	9%	10%	9%	7%
LDV (private)	43%	24%	17%	32%	35%
Public Transport	8%	19%	24%	15%	12%

2.4. Conclusion – Analysis of published scenarios

In summary, the methodology of the analysed energy and mobility scenarios vary significantly and cannot be directly compared. The projection of the transport demand and supply in energy scenarios tend to be top-down and lack a detailed demand analysis. While mobility scenarios are predominantly detailed bottom up assessment of the regional transport demand. Some of which have a very high technical resolution in regard to the transport modes. Some mobility scenarios include walking and cycling and whether the purpose of the travelling is for work (= commuting) or leisure. This level of detail is not possible for global and regional energy scenarios.

However, mobility scenarios are focused on the transport sector and do not take other parts of the energy sector into account. Therefore, energy scenarios are useful to estimate the overall energy supply requirements – in regard to fuels and/or electricity- as well as the regional carbon budget in relation to other industries.

Energy and mobility scenarios can support each other in regard of future planning of the transport sector:

- Energy scenarios provide the overall context in regard of the carbon budget and available energy supply.
- Mobility scenarios provide the bottom up analysis for the transport demand and regional options for transport mode shifts such as from road to rail. Local knowledge is required in regard to the available infrastructure such as exiting tracks or bike lanes etc.

Energy and mobility scenario are complementary and can support each other for the development of a sustainable transport system on a local, regional and international level.

2.5. Mobility Energy scenarios

As a result of this analysis, UTS/ISF recommends to develop Mobility AND Energy Pathways (MAEP). A MAEP combines a detailed bottom up transport demand analysis with a defined carbon budget. The required energy demand - in regard of fuels and or electricity - and will feed back into a wider energy scenario to combine the advantages of a mobility with those of energy scenarios.

Required data

In order to develop a demand analysis that feeds into the energy and mobility scenario, a reliable database is required. The following parameters are needed and either not available, not complete or vary significantly for the same region due to the lack of standardized data collection methods:

- Travelled passenger kilometer by region and transport mode in passenger kilometer per year [pkm/a]

- Fright transport kilometer by transport mode and region in ton-kilometer per year [tkm/a]

- Regional status of the available infrastructure:
    - Rail – current capacity utilisation
    - Road – current capacity utilisation
    - Bike lanes and footpaths – possibilities to increase utilisation

- Average length and frequencies of travel demand – especially in regard to commuters.


Z
Z

3. The global carbon budget for the transport sector to achieve the 1.5°C target

Beyond reasonable doubt, climate change has been driven by anthropogenic activities over the last 250 years. In fact, the human-induced release of GHGs into the atmosphere is the cause behind the already observed climate change. The reason that climate change is not even greater than it is that some human-induced changes mask some of the warming attributable to elevated GHG concentrations. This masking effect arises from the emission of cooling aerosols and changes in land use that increase the reflectivity of the earth's surface. The following section 3.1 is taken from the research work "Achieving the Paris Climate Agreement" (Meinshausen et.al. 2019[18]).

3.1. Carbon budget and future warming

Although the anthropogenic contribution to climate change occurs via a large set of GHG emissions and multiple aerosols and land-use changes, there is one dominant influence: carbon dioxide (CO_2) emissions.

It is not only the magnitude of the anthropogenic emissions of CO_2 that makes it such a significant driver of human-induced climate change. There is also an inherent difference between CO_2 and almost all other GHGs and aerosols. Over the time scales of interest here, CO_2 does not have a finite lifetime in the atmosphere. All other gases react chemically, become photodissociated in the stratosphere, or are, for example, consumed by the bacteria in soils. However, once CO_2 is released from the near-permanent carbon pools of fossil fuel reservoirs, it only travels between a set of 'active' carbon pools. These active pools are the land biosphere, the ocean, and the atmosphere. Therefore, if CO_2 is added to one, the level in all three pools will rise and over time, a new, higher equilibrium concentration is reached. For example, whereas CO_2 is consumed by plants during the photosynthesis process and then built into plant tissue as carbon, this same carbon is released again as CO_2 when forests burn, when organic matter in the soil decomposes, and when humans and other animals oxidize the food they eat. Therefore, a kilogram of CO_2 emissions will increase the atmospheric CO_2 concentration for hundreds or even thousands of years. Initially, the average CO_2 concentration will shoot up by that kilogram and then drop relatively quickly again before a new equilibrium is slowly re-established by the redistribution of carbon into the land biosphere and the ocean.

The IPCC Fifth Assessment Report (AR5) notes that three effects (the carbon cycle and its feedbacks, the saturation effect of forcing, and the delayed response of the atmosphere to warming) combine to create what is almost a stepwise function in the warming caused by CO_2 emissions. In other words, every extra kilogram of CO_2 produces a slightly greater increase in temperature than the preceding kilogram, and the warming effect is much the same 10 years after the emission of that kilogram as it is after 100 or 500 years. Over time, less of the CO_2 will remain in the atmosphere, but the Earth's inertia will still cause the temperature to reflect the extra warmth arising from the initial emission.

This feature of the Earth's warming and the carbon cycle can be exploited to derive a very simple linear relationship between cumulative carbon emissions and warming. In fact, the resultant warming is a simple function of the sum of all the CO2 that has ever been emitted, largely independent of when a certain amount of CO2 was emitted in the past. Based on this understanding, we can compute the carbon budgets for specific levels of warming. As a complication, of course, an unknown amount of warming arises in response to other GHG emissions and aerosols. When deriving carbon budgets, this extra level of warming is normally derived from a range of future emission scenarios. Therefore, the ultimate level of warming is the sum of the linear CO2-induced warming level (often described as the 'transient climate response to cumulative emissions of carbon') and a smaller and somewhat uncertain contribution that depends on the other GHGs and aerosols.

'Since AR5, estimates of remaining carbon budgets have been improved by a new methodology first presented in SR1.5[19], updated evidence, and the integration of results from multiple lines of evidence. A comprehensive range of possible future air pollution controls in scenarios is used to consistently assess the effects of various assumptions on projections of climate and air pollution. A novel development is the ability to ascertain when climate responses to emissions reductions would become discernible above natural climate variability, including internal variability and responses to natural drivers' (IPCC AR6SPM 2021).

Every tonne of CO2 emissions adds to global warming

Global surface temperature increase since 1850-1900 (°C) as a fuction of cumulative CO2 emissions (GtCO2)

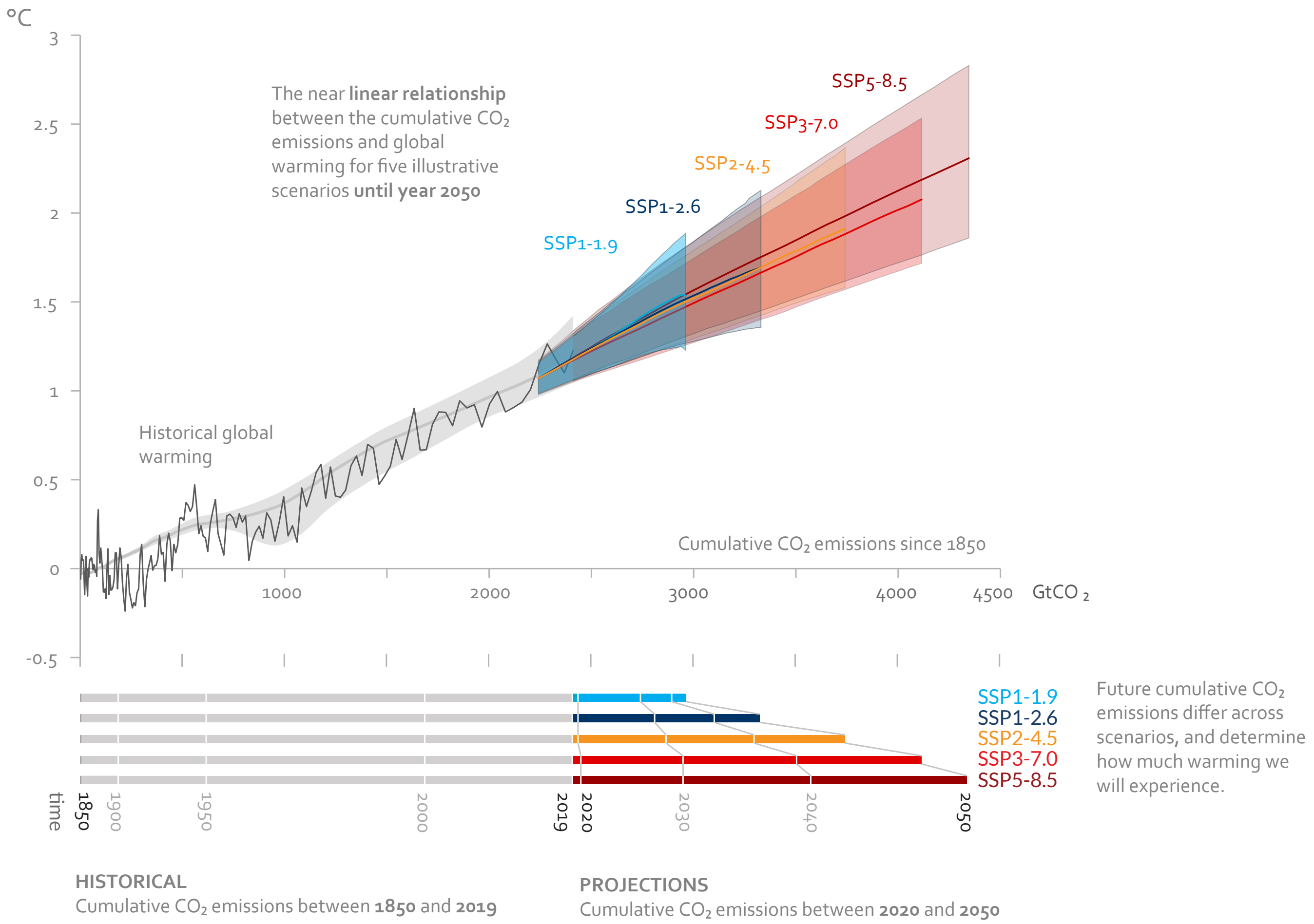


Figure 13. IPCC AR6-SPM: Relationship between cumulative CO2 emissions and global surface temperature

3.2. IPCC Assessment Report 6

Figure 13 shows a graph published in the Summary for Policymakers (SPM) of Assessment Report 6; it illustrates the near-linear relationship between the cumulative CO_2 emissions and global warming for five scenarios until 2050. The IPCC describes the figure as follows:

Top panel: Historical data (thin black line) shows observed global surface temperature increase in °C since 1850–1900 as a function of historical cumulative carbon dioxide (CO_2) emissions in GtCO_2 from 1850 to 2019. The grey range with its central line shows a corresponding estimate of the historical human-caused surface warming (...). Colored areas show the assessed very likely range of global surface temperature projections, and thick colored central lines show the median estimate as a function of cumulative CO_2 emissions from 2020 until the year 2050 for the set of illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.) Projections use the cumulative CO_2 emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcers. The relationship is illustrated over the domain of cumulative CO_2 emissions for which there is high confidence that the transient climate response to cumulative CO_2 emissions (TCRE) remains constant, and for the time period from 1850 to 2050, during which global CO_2 emissions remain net positive under all illustrative scenarios as there is limited evidence supporting the quantitative application of TCRE to estimate temperature evolution under net negative CO_2 emissions.

Bottom panel: Historical and projected cumulative CO_2 emissions in GtCO_2 for the respective scenarios.

3.3. Carbon budgets for 1.5°C and 2.0°C warming

The IPCC Sixth Assessment Report used the results of earth system models to derive it's carbon budgets. Earth system models are the most complex computer models we have of how the earth, its atmosphere, oceans, and vegetation are interacting with each other. The IPCC investigated the amounts of cumulative carbon emissions (in a multi-gas world) that would be consistent with, for example, temperatures maintained below either 1.5°C or 2.0°C higher than pre-industrial levels. The IPCC Special Report on the 1.5°C degree target (IPCC 2018)[21] cites different carbon budget numbers, depending on whether a low estimate of historical temperatures is assumed or surface air temperatures are consistently applied. Therefore, there is some complexity and uncertainty around the carbon budget, which is related to the fact that different interpretations can be made about how far we are still away from the 1.5°C target (for example). If we assume that we are still 0.63°C away from 1.5°C warming (a very optimistic estimate, which is unfortunately based on a too optimistic account of historical emissions), from January 2018 onwards, we can still emit 1,320 GtCO_2 before reaching 2°C warming (66% chance) and 770 GtCO_2 before reaching 1.5°C warming (50% chance). These figures must be reduced by a further 100 GtCO_2 to account for the additional earth system feedback that has occurred over the 21st century. However, when a more realistic measure of historical temperature evolution is used (i.e., calculated by consistently using proxies for surface air temperatures over the land and ocean, rather than by mixing ocean surface water temperatures with air temperatures over land), the carbon budgets are no longer very high. Specifically, the carbon budget required to maintain the Earth's temperature below 2°C, with 66% probability, then decreases to 1,170 GtCO_2 from January 1, 2018 onwards and to 560 GtCO_2 for a 50% chance of staying below 1.5°C (before the extra 100 GtCO_2 that must be subtracted for additional earth system feedbacks is considered; see Table 2.2 in the IPCC Special Report on 1.5°C warming).

The latest IPCC AR 6 report (IPCC 2021)[22] largely confirms these numbers and updated the base-year to 2020 (Table 10).

Recent effects of climate change provide another set of stark reminders that it is more urgent than ever to replace fossil fuels. If we wait for the bushfire seasons that will occur at global warming levels of 1.5°C or 2°C, with intensified droughts or ever-more intense hurricanes, it might be much too late to avoid their widespread catastrophic impacts. Even at 1.5 °C warming, there is a risk that the continuous melting of the Greenland ice sheet will cause sea levels to rise by meters over the coming centuries. Fossil fuels have undoubtedly allowed great growth in prosperity across the globe, but their replacement with the cleaner, cheaper, and emission-free technologies that are available today is overdue.

Table 10. IPCC AR6 - Estimates of historical CO2 emissions and remaining carbon budgets

Global warming between 1850–1900 and 2010–2019 (°C)		Historical cumulative CO_2 emissions from 1850 to 2019 ($GtCO_2$)					
1.07 (0.8–1.3; likely range)		2390 (± 240; likely range)					
Approximate global warming relative to 1850–1900 until temperature limit (°C) *(1)	Additional global warming relative to 2010–2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 to 2050 ($GtCO_2$)					**Variations in reductions in non-CO_2 emissions*(3)**
		Likelihood of limiting global warming to temperature limit*(2)					
		17%	33%	50%	67%	83%	
1.5	0.43	900	650	500	400	300	Higher or lower reductions in accompanying non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ o more
1.7	0.63	1,450	1,050	850	700	550	
2.0	0.93	2,300	1,700	1,350	1,150	900	

*(1) Values at each 0.1°C increment of warming are available in Tables TS.3 and 5.8 (see SPM, AR6)
*(2) This likelihood is based on the uncertainty in transient climate response to cumulative CO2 emissions (TCRE) and additional earth system feedbacks, and provides the probability that global warming will not exceed the temperature levels provided in the two left columns. Uncertainties related to historical warming (±550 GtCO2) and non-CO2 forcing and response (±220 GtCO2) are partially addressed by the assessed uncertainty in TCRE, but uncertainties in recent emissions since 2015 (±20 GtCO2) and the climate response after net zero CO2 emissions are reached (±420 GtCO2) are separate.
*(3) Remaining carbon budget estimates consider the warming from non-CO2 drivers as implied by the scenarios assessed in SR1.5. The Working Group III Contribution to AR6 will assess mitigation of non-CO2 emissions.

3.3.1. Shared Socioeconomic Pathways (SSPs)

Shared Socioeconomic Pathways (SSPs) are being used as important inputs for the latest climate models, feeding into the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report. Those scenarios model different greenhouse gas emission scenarios, with regard to either reduction or increase of those emissions by the end of this century (2100). They are also being used to explore how societal choices will affect greenhouse gas emissions and, therefore, how the climate goals of the Paris Agreement could be met (CB 2018)[23].

There are various SSP scenarios – from SSP1 to SSP 8.5. Basically, the higher the number, the higher the emission between 2020 and 2100 and the higher the estimated temperature increase. Furthermore, there are different categories of SSP in regards to the assumption as to whether or not carbon emissions are emitted and – mainly after 2030 – removed from the atmosphere with technical applications such as Carbon Sequestration and Storage (CCS). The One Earth Climate Model (OECM) used for this analysis focuses on SSP1 scenarios only. The OECM scenario remains within a carbon budget of 400 Gt CO2 between 2020 and 2050 in order to limit global warming to + 1.5°C with 67% likelihood and does not factor in an 'overshoot'. An overshoot is the theoretical assumption that more CO2 can be emitted (as 400 Gt) and that the surplus can be removed (essentially by the generation that follows) using technical measures such as CCS. CCS technology has been under development for over 30 years but has not yet led to any market competitive technology. The OECM does not include speculative technologies which are far from cost competitive.

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3.4. Sectorial carbon budgets (update)

According to the IEA Energy Technologies report (IEA ETP 2020)[24] road travel accounts for three-quarters of transport emissions; 45.1% from passenger vehicles, including cars and buses, and 29.4% from trucks carrying freight. The entire transport sector accounts for 21% of total emissions; road transport accounts for three-quarters of transport emissions while road transport accounts for 15% of total CO_2 emissions.

Currently, aviation consumes 5% of the total global transport energy demand and navigation 2.2%. In regard to emissions, aviation accounts for 11.6% of transport emissions, just under one billion tonnes of CO_2 each year or around 2.5% of total global emissions. International shipping contributes a similar amount, at 10.6% of global energy-related CO_2 emissions per year. Rail travel and freight is responsible for only 1% of transport emissions. Other transport, mainly the movement of materials such as water, oil, and gas via pipelines, is responsible for 2.2%. This research builds on a previous interdisciplinary project led by ISF that modeled sectoral and regional decarbonization pathways to achieve the Paris climate goals—to hold global warming to well below 2 °C and to "pursue efforts" to limit it to 1.5 °C. That project produced the One Earth Climate Model (OECM), a detailed bottom-up examination of the potential to decarbonize the energy sector. The study focused on the ways in which humans produce energy, because energy-related carbon dioxide (CO_2) emissions are the main driver of climate change (Teske et. al 2019)[25].

Furthermore, the carbon budget for the global transport sector has been assessed in more detail – and in the context of other major sectors – buildings and industry – with a focus on hard-to-abate-sectors: Aviation, shipping, steel, and the cement industry (Teske et. al. 2020)[26].

Table 11. Global cumulative energy-related CO_2 emissions [$GtCO_2$] between 2020 and 2050

Cumulative energy-related CO_2 emissions [$GtCO_2$]		
Global		Transport Sector
		Share of cumulative emissions 2020–2050
	2020–2050	[%]
Industry	**77**	**19%**
• Cement	9	2%
• Steel	19	5%
Transport (including power for transport)	**115**	**29%**
• Aviation (incl. international)	11	3%
• Navigation (incl. international)	19	5%
• Rail	3	1%
• Road	82	21%
Power (excluding power for transport)	**107**	**27%**
Buildings/Other Sectors	**93**	**23%**
Other Conversions	8	2%
Total Actual CO_2 Emissions	**400**	**100%**

Table 11 shows the global cumulative CO_2 emission under 1.5°C for the four main sectors: Buildings, industry, power generation, and transport.

The percentage of the transport sector in regard to overall carbon budget varies significantly by region. The reasons are diverse: The share of renewables for power generation, the level of efficiency of the industry and building sector, and whether the transport sector is likely to increase or decrease are the main factors.

Africa, for example, has a relatively low share of transport CO_2 emissions in relation to rest of the energy industry, but transport demand and the level of individual transport is expected to increase with economic expansion. While OECD North America will move from a very high percentage of transport-related CO_2 emissions – mainly from cars – towards very low shares within one decade due to the electrification of the transport system. In sum, the transport sector still has a high share on the overall carbon budget due to the emissions over the next 5 to 10 years.

Table 12 shows the cumulative energy related CO_2 emissions for the 10 world regions analyzed between 2020 and 2050. In order to stay within a maximum temperature increase of 1.5°C (66% likelihood).

Table 12. Cumulative energy-related CO_2-emissions

Cumulative energy related CO_2 emissions 2020-2050 - 1.5˚C pathway				
Region	Total [Gt CO_2]	Region share	Transport [Gt CO_2]	Transport Share
World 1.5 C	**400**		**110**	**26%**
International Bunker			14	13%
OECD North America 1.5 C	57	14%	31	28%
Latin America 1.5 C	15	4%	7	6%
OECD Europe 1.5 C	38	9%	13	12%
Africa 1.5 C	22	5%	5	5%
Middle East 1.5 C	31	8%	5	4%
Eurasia 1.5 C	32	8%	5	5%
Non-OECD Asia 1.5 C	30	7%	7	6%
India 1.5 C	36	9%	4	4%
China 1.5 C	119	30%	13	12%
OECD Pacific 1.5 C	22	5%	6	5%

In order to reduce transport-related carbon emissions to zero, a complete decarbonization of the transport energy itself is required. During the transition towards 100% renewable transport fuels, a mix of technical efficiency and decreased transport demand is needed to keep the overall carbon emissions low.

The global carbon budget for the transport sector – based on the presented analysis – is estimated with 110 Gt CO_2 between 2020 and 2050 – about 26% of the remain carbon budget of 400 Gt CO_2.

The majority of this carbon budget – 20% to 25% of the total global carbon budget – is estimated to be required for the road transport sector.


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4. TUMI Transport Outlook 1.5°C: Methodology

The development of the global scenario within the TUMI Transport Outlook 1.5°C is based on the One Earth Climate Model (OECM) (Teske et.al 2019[27]), a comprehensive literature & scenario review (see Chapters 1 and 2) and two multi-stakeholder workshops organized by GIZ and UTS/ISF in June and September 2021.

As a result, the OECM methodology has been expanded in order to achieve a higher level of accuracy and resolution, both in the area of the transport demand projection and in the regional and global transport energy demand calculation. The effects on energy-related CO_2 emissions are calculated in a last step.

The demand projection is focused on a bottom-up approach. The actual cause of passenger transport demand e.g., to get groceries or to commute for work or for leisure and recreation leads to a transport demand in kilometer per person and year. The development of this transport demand is dependent on a number of different factors, among the most important of which are the actual population development and their economic situation. Geography and lifestyle play an important role as well. For the transport of goods, it is important where the required groceries or goods are produced, what resources are needed, and where they are located. Economies with high local production rates have lower transport demands than those with high import/export dependencies. However, the calculation of the actual transport demand is based on non-energy-related factors. A transport or travel demand as such, does not necessarily lead to an energy demand if a non-energy-transport-mode such as walking or cycling is chosen – sufficient to satisfy the demand. However, most transport modes need energy, the amount of energy per kilometer depending upon the energy intensity of the chosen vehicle.

Finally, the demand for transport energy does not inevitably lead to CO_2 emissions if the energy is generated from renewable electricity and/or renewable fuels. Thus, a carbon neutral global transport sector is possible while maintaining regional and intercontinental travel as well as global trade.Figure 14 provides a simplified overview about the cause and effect of the transport demand which leads to transport service needs. Transport demand is dependent on a huge number of factors – the most important of which are population and the economic situation. In general, the more people and the higher the economic standard, the higher the transport demand.

The transport service structure – and therefore the transport mode – depends on a variety of factors as well. The actual travel distance, the required travel time, the availability of certain transport modes and the costs, among other factors, define the chosen transport modes. Each transport mode has a variety of vehicles with different energy intensities. The transport mode 'road' for example has by far the largest amount of different vehicle options: buses, a huge variety of car types with different drivetrains, motorcycles, bicycles, and even walking.

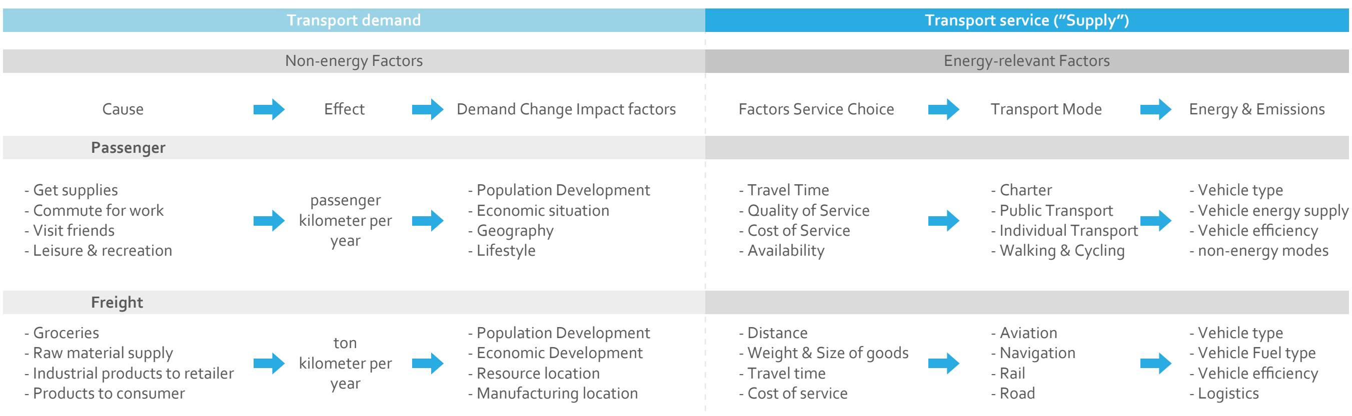

Figure 14. Cause & effect of transport demand and implication of energy demand and CO_2 emissions


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A global scenario needs to simplify the transport demand projection. A detailed analysis of the purpose of each of those transport demands in kilometers per day for the entire population is not possible. Therefore, the methodology focuses on the development of regional person and tons of kilometers per year. The main factors for demand changes are population and economic development. There are different developments and assumptions for each of the 10 world regions. The following section documents the actual model structure and the calculation process.

4.1. Transport demand

The calculation of the transport demand is based on a two-step approach:

1. Calibration of the model with statistics from the past 10 to 15 years (Table 13);

2. Projection of transport demand based on changing demand in km and energy intensities by transport mode (Table 14).

In order to calibrate the model, the transport demand of the past decade is recalculated on the basis of the available energy statistics. The International Energy Agencies' (IEA) 'Advanced World Energy Balances' provides the total final energy demand by transport mode – aviation, navigation, rail, and road – by country, region, or globally. However, there is no further specification of the energy usage within each of the transport modes. A further division into passenger and freight transport is therefore calculated using percentage shares. These proportions are determined through a literature review, as well as via the average energy intensity for each of the transport modes for passenger and freight vehicles.

The annual energy demand divided by the average energy intensity by mode leads to the annual transport demand in passenger [pkm/a] and ton kilometer per year [tkm/a]. Those results are then compared to the OECD transport statistic which provides both parameters – pkm/a and tkm/a. Calibrating the model on the basis of historical data ensures that the basis of the scenario projection for the coming years and decades has been correctly mapped and that the changes can be calculated more realistically.

Table 13. Calibration for transport demand calculation

Calculation Concept	Process	Until 2020	UNIT	Comment
Transport Demand				
Aviation / Navigation / Rail / Road – Past to Present				
Annual Demand	Data	Data base	[PJ/a]	Data: IEA Advanced World Energy Balances
Passenger share	Input	Literature	[%]	Shares from total energy demand from literature
Freight share	Input	Literature	[%]	Shares from total energy demand from literature
Average Energy intensity - passenger transport	Data	Literature	[MJ/pkm]	Literature review - based on current supply mix
Average Energy intensity - freight transport	Data	Literature	[MJ/tkm]	Literature review - based on current supply mix
Passenger kilometer	Calculation	= Annual Demand / Energy Intensity	[pkm]	Comparison with OECD statistic
Ton-Kilometer	Calculation		[tkm]	Comparison with OECD statistic
Annual Growth/Decrease - Passenger kilometer	Calculation	= Annual Demand previous year/ Annual Demand calculated year	[%/a]	Calculated to understand the trend between 2005 and 2020
Annual Growth/Decrease - Ton-Kilometer	Calculation		[%/a]	
Population - Indicator for passenger transport development	Data	Data base	[million]	Data: UN
GDP / capita - Indicator for passenger & Freight transport development	Data	Database	[$GDP/capita]	Data: World Bank
GDP - Indicator for freight transport development	Data	Data base	[$GDP]	Data: World Bank

Table 14. Projection of transport demand based on changing demand in km

Process	2020 to 2050	UNIT	Comment
Aviation / Navigation / Rail / Road - Projection			
Calculation	= (Passenger km previous year) X (in/decrease in %/a)	[pkm]	Starting point: Base year 2019
Calculation	= (Ton km previous year) X (in/decrease in %/a)	[tkm]	Starting point: Base year 2019
Input	INPUT in %/a	[%/a]	Assumption
Input	INPUT in %/a	[%/a]	Assumption
Calculation	INPUT in %/a	[million]	Assumption based on UN projection
Calculation	= $GDP / Population	[$GDP/capita]	
Calculation	INPUT in %/a	[$GDP]	Assumption based on World Bank Projection
Result	Time series 2020 - 2050: Passenger km per year & region	[pkm/a]	Input for energy demand calculation
Result	Time series 2020 - 2050: Freight km per year & region	[tkm/a]	Input for energy demand calculation

4.2. Transport service: Energy demand calculation

Just like the transport demand calculation, the transport energy demand and supply calculation begins with model calibration based on historical data as part of a two-step approach:

Step 1: Calibration of the model with statistic from the past 10 to 15 years (Table 15);

Step 2: Projection of transport supply: Based on transport mode and vehicle specific parameters (Table 16).

Besides the final energy demand for each transport mode, the IEA Advanced World Energy Balances also provides the energy demand by source – oil, gas, biofuels, and electricity. In order to be able to calculate the exact energy requirement for each transport mode with the respective transport requirement (in km) assuming different vehicle technologies, the status quo must be determined. For this purpose, the respective transport energy requirement for each transport mode and fuel type is calculated on the basis of current vehicle technology market shares and technology specific energy intensities per kilometer. The result is a technology-specific illustration of each sector. Table 15 provides an overview about the calculation process for the model calibration.

Future energy demands on the basis of the projected passenger and freight kilometer are calculated via market shares and technology specific energy intensities. The overall transport energy demand e.g. in passenger kilometer is distributed in a first step to each transport mode. Mode shift from road to rail can be assumed and the sector specific demand is further distributed to specific vehicle types – again via assumptions of market shares.

Table 15. Calibration for transport demand calculation

Transport Supply				
Aviation / Navigation / Rail / Road - Past to Present				
Annual Demand - oil	Data	Database	[PJ/a]	Data: IEA Advanced World Energy Balances
Divide into passenger and freight transport	Input	Literature	[%]	Shares from total energy demand from literature
Average energy intensity - passenger	Input	Literature	[MJ/pkm]	Average energy intensity for respective fuel
Average energy intensity - freight	Input	Literature	[MJ/tkm]	Average energy intensity for respective fuel
Repeat process above for natural gas, biofuels, synthetic fuels, hydrogen and electricity				
Add up all energy carriers by transport mode to calculate the total energy demand for aviation / navigation / rail / road				
Add up all energy demand by transport mode to calculate the total energy demand for transport				

Table 16. Projection of transport supply: Based on transport mode and vehicle specific parameter

Transport Energy Projection			
Aviation / Navigation / Rail / Road			
From calibration	Energy demand Aviation	[PJ/a]	Based on statistic / database
From calibration	Energy demand Aviation - share passenger	[%]	
From calibration	Average energy intensity of oil using vehicles	[MJ/pkm]	
Repeat for all fuels, all sectors (passenger & freight)			
Repeat process above for remaining transport modes: navigation, rail and road			
Projection			
Input	passenger transport demand - aviation	[pkm/a]	Input demand projection
Input	market share vehicle type 1	[%]	Possible efficiency increases over time
Input	market share vehicle type 2	[%]	Possible efficiency increases over time
Input	market share vehicle type n	[%]	Possible efficiency increases over time
Input	energy intensity vehicle type 1	[MJ/pkm]	Possible efficiency increases over time
Input	energy intensity vehicle type 2	[MJ/pkm]	Possible efficiency increases over time
Input	energy intensity vehicle type n	[MJ/pkm]	Possible efficiency increases over time
Calculation	pkm per year X market share type 1 X energy intensity type 1 - energy demand for vehicle type 1		
Calculation	Repeat for all vehicle types		
Calculation	Calculate total energy demand vehicle 1 - n		
Result	Energy demand by transport mode		
Repeat for all transport modes			

4.3. Technical parameters

Energy intensities for different vehicle types and for each of the available drivetrains play an important role both for the calibration of the mode, as well as for projections. Each transport mode has various different vehicle options. Each of the vehicles have different drivetrain and efficiency options. The technical variety of passenger vehicles for example, is extremely large. The engine size for 5-seater cars ranges from around 20 kW to over 200 kW. Additionally, drive trains can use a range of fuels, from gasoline, diesel, and bio diesel to hydrogen and electricity. Each vehicle has different energy intensities in MJ/pkm. Thus, the energy intensities provided in the following tables are average values.

4.3.1. Individual transport

Passenger transport via road makes up by far the most common and most important form of travel. There are numerous technical options to 'move people with vehicles': Bicycles, motorcycles, tricycles, city cars, 4-wheel drive SUVs – each vehicle has very different energy intensity per km. While this research project aims for high technology resolution, simplifications are required. First and foremost, the data for all existing vehicles for each of the regions and for the global level are neither available nor practical to use. Table 17 shows energy intensities for the main vehicle types and formed the basis for the energy scenario calculation.

Table 17. Energy intensities individual transport – road transport

Individual Transport			Passengers		Vehicle Demand	Consumption per Passenger	Energy Demand
			Average Passengers per Vehicle	Assumed Occupation Rate	Average	Average	Assumption for Scenario Calculation
		Fuels			litre/100 km	litre/100 pkm	[MJ/pkm]
Scooters & motor-bikes	2-wheeler	Gasoline	1	1	3.0	3.0	1.21
		Electricity			kWhel/100 km	kWhel/100 pkm	[MJ/pkm]
E-bikes	2-wheeler	Battery	1	1	1.0	1.0	0.04
Scooters	2-wheeler	Battery	1	1	1.8	1.9	0.06
Motor-bikes	2-wheeler	Battery	1	1	4.8	2.4	0.17
Rickshaw	3-wheeler	Battery	3	2	8.0	4.0	0.14
		Fuels	0	0	litre/100 km	litre/100 pkm	[MJ/pkm]
Cars	small	ICE-oil	2	1.8	5.0	2.8	1.12
	medium	ICE-oil	4	2	7.5	3.8	1.51
	large	ICE-oil	5	2	10.5	5.3	2.11
	small	ICE-gas	2	1.8	4.5	2.5	0.63
	medium	ICE-gas	4	2	7.0	3.5	1.41
	large	ICE-gas	5	2	10.0	5.0	1.25
	small	ICE-bio	2	1.8	5.0	2.8	0.91
	medium	ICE-bio	4	2	7.5	3.8	1.51
	large	ICE-bio	5	2	10.5	5.3	1.72
	small	Hybrid-oil	2	1.8	4.0	2.2	0.89
	medium	Hybrid-oil	4	2.5	6.0	2.4	0.96
	large	Hybrid-oil	5	2.5	8.5	3.4	1.37
		Electricity			kWhel/100 km	kWhel/100 pkm	[MJ/pkm]
	small	Battery	2	1.8	16.0	8.9	0.32
	medium	Battery	4	2	25.0	12.5	0.45
	large	Battery	5	2	32.5	16.3	0.59
	large	Fuel Cell	4	2	37.5	18.8	1.36

4.3.2. Public transport over land

There is a wide variety of public transport vehicles ranging from rickshaws to taxis, minibuses to long distance trains. The occupation rate for those vehicles is key to calculating the energy intensity per passenger kilometer. A diesel-powered city bus with a transport of 75 passengers, for example, needs – on average – about 27.5 liters per 100 kilometers. If the bus is operating at full capacity during peak hours, the energy demand per passenger is as low as 400ml per kilometer – lower than almost all other fossil fuel-based road transport vehicles. However, if the occupancy drops to 10% - e.g. for a night bus – the energy intensity rises to 3.7 liters – equal to a small energy efficient car.

Occupation rates vary significantly and depend on the time of the day, weekdays, and seasons. Furthermore, there are significant regional differences even within a single country. Even more so across larger regions such as OECD Europe, which is composed of over 30 countries from Iceland to Turkey. Again, the parameters shown in Table 18 are simplified averages and are further condensed for the scenario calculation. While the high technical resolution would be possible for the scenario model, it would imply an accuracy that does not exist, because the statistical data required for this are not available on a regional and global level.

Table 18. Energy intensities public transport – road & rail transport

Public Transport			Passengers		Vehicle Demand	Consumption per Passenger	Energy Demand
			Average Passengers per Vehicle	Assumed Occupation Rate	Average	Average	Assumption for Scenario Calculation
		Fuels			**litre/100 km**	**litre/100 pass-km**	**[MJ/pkm]**
Buses	small	Diesel	12	40%	8.8	1.8	0.73
	small	Bio	12	40%	8.8	1.8	0.60
	12 m	Diesel	75	40%	27.5	0.9	0.37
	12 m	Bio	75	40%	27.5	0.9	0.30
	large	Diesel	135	40%	57.5	1.1	0.43
		Electricity	0	0	kWhel/100 km	kWhel/100 pkm	[MJ/pkm]
	small	Battery	12	40%	31	6.4	0.23
	small	Fuel Cell	12	40%	77	15.9	0.57
	12 m	Battery	75	40%	143	4.8	0.17
	12 m	Fuel Cell	75	40%	358	11.9	0.43
	large	(Overhead-) lines	135	40%	263	4.9	0.18
		Fuels	0	0	litre/100 km	litre/100 pkm	[MJ/pkm]
Trains	Metros	Diesel	400	40%	150	0.9	0.38
	Metros	Bio	400	40%	150	0.9	0.31
	Commuter Trains	Diesel	600	40%	300	1.3	0.50
	Commuter Trains	Bio	600	40%	300	1.3	0.41
		Electricity	0	0	kWhel/100 km	kWhel/100 pkm	[MJ/pkm]
	Trams	Electric	300	40%	495	3.8	0.14
	Metros	Electric	300	40%	1,200	4.0	0.14
	Commuter Trains	Electric	600	40%	1,950	4.8	0.17

4.3.3. Freight transport

The freight transport energy intensities data are not as diverse as for passenger transport, as the transport vehicle types are more standardized and the fuel demand is well known. However, the utilization rate of the load capacity varies significantly and consistent data is not available for the calculated regional and global level. Thus, the assumed utilization rate has a huge influence on the calculated energy intensity per ton-km. The average energy intensities per ton-kilometers used in the scenario are shown in Table 19 and are largely in line with other sources from the scientific literature. The assumed energy intensity for electric and fuel cell / hydrogen freight vehicles are indicative only as this technology is still in the demonstration phase. Therefore, all scenarios calculated do not factor in large shares of electric freight transport vehicles before 2035.

Table 19. Energy intensities freight transport – road & rail transport

Freight Transport			Max Load Capacity in tons	Assumed Utilisation Rate	Vehicle Demand	Consumption per ton	Energy Demand
					Average	Average	Assumption for Scenario Calculation
		Fuels			litre/100 km	litre/ton-km	[MJ/pkm]
Trucks	3.5t	Diesel	3.5	40%	11	7.9	3.16
	3.5t	Bio	3.5	40%	11	7.9	2.57
	7.5t	Diesel	7.5	40%	20	6.5	2.61
	7.5t	Bio	7.5	40%	20	6.5	2.13
	12.5t	Diesel	12.5	40%	25	5.0	2.01
	12.5t	Bio	12.5	40%	25	5.0	1.64
		Electricity			kWhel/100 km	kWhel/ton-km	[MJ/pkm]
	3.5t	Battery	3.5	40%	19	13.6	1.34
	3.5t	Fuel Cell	3.5	40%	46	33.2	1.33
	7.5t	Battery	7.5	40%	41	13.6	0.49
	7.5t	Fuel Cell	7.5	40%	100	33.2	1.19
	12.5t	Battery	12.5	40%	68	13.6	0.49
	12.5t	Fuel Cell	12.5	40%	166	33.2	1.19
Trains		Fuels			litre/100 km	litre/ton-km	[MJ/pkm]
	Freight - 740m	Diesel	1,000	40%	300	0.8	0.30
	Freight - 740m	Bio	1,000	40%	300	0.8	0.25
		Electricity			kWhel/100 km	kWhel/ton-km	[MJ/pkm]
	Freight - 740m	Electric	1,000	40%	5,840	14.6	0.53


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5. TUMI Transport Outlook 1.5°C: Assumptions and Narratives

The TUMI Transport Outlook 1.5°C aims for a clearly defined carbon budget to achieve the Paris Climate Agreement. This section provides an overview about the socio-economic assumptions and briefly describes the current situation of the global transport sector. The most recent complete statistical data set for all 10 calculated world regions available is from 2019, although initial data for 2020 is available. This chapter is based on J. Pagenkopf et.al 2019[28] and has been updated and modified to reflect the changes made for the TUMI Outlook.

5.1. Socio-economic assumptions

The assumed population development is based on the projection of the United Nations Department of Economic and Social Affairs while the GDP development is based on World Bank projections (see table 20).

5.2. Global transport – status quo 2020

The global pandemic started in early 2020 and led to significant travel restrictions across the world. At the time of this writing – September 2021 – travel restrictions in many countries were still in place.

Global oil demand accounted for 11.5 Gt of energy related CO_2 in 2019 (IEA 2020)[29]. The transport sector consumes 65% of total oil consumption – this includes oil for international bunkers (10.4% of total oil demand). Road transport consumed more than 40% of all oil demand in 2019. The sector's growth has been responsible for over half of total oil demand growth since 2000 (BNEF 2020)[30]. As a result of restricted mobility to stop spread of the virus, the global pandemic led to a significant drop in oil demand especially for road transport and aviation, which are responsible for nearly 60% (IEA 2020)[31] of oil use. In 2020, global oil demand is estimated to have dropped by 8%. During the time of writing, the global pandemic was still ongoing although travel restrictions have been relaxed in many countries, the result of which was an increase in transport demand as compared to 2020. In our transport demand projections, we assume that the demand will continue to increase to pre-pandemic levels by 2025.

The pandemic had a dramatic impact on public transport: Fear of being infected with COVID-19 led many people to avoid using public transport and switch to other transport modes – especially individual transport such as private cars or (electric) bicycles.

The report The Future of Public Transport (C40 Cities 2021)[32] published in March 2021 finds that as "public transport ridership has fallen during the COVID-19 pandemic, so has revenue. Public transport agencies across cities worldwide face a critical funding shortfall that threatens jobs and services."

The energy demand is likely to increase and there is currently no sign that these increases will slow down in the near future. The increasing demand for energy for transport has mainly been met by greenhouse gas (GHG)-emitting fossil fuels.

Table 20. Socio-Economic Assumptions by region 2020 to 2050

Assumed Population and GDP Development by region 2020 to 2050							
		Unit	2019	2025	2030	2040	2050
OECD North America	Population	[million]	499	524	543	575	599
	GDP	[billion $]	24,255	27,650	30,513	37,562	45,788
Latin America	Population	[million]	526	552	571	599	616
	GDP	[billion $]	7,415	8,807	10,141	13,761	18,675
OECD Europe	Population	[million]	579	587	592	598	598
	GDP	[billion $]	23,433	26,076	28,269	32,807	36,963
Africa	Population	[million]	1,321	1,522	1,704	2,100	2,528
	GDP	[billion $]	6,865	9,247	11,376	17,498	26,403
Middle East	Population	[million]	250	276	295	331	363
	GDP	[billion $]	6,120	7,230	8,857	12,112	17,587
EurAsia	Population	[million]	346	347	346	343	339
	GDP	[billion $]	6,685	7,919	9,081	11,853	15,025
NON-OECD Asia	Population	[million]	1,189	1,269	1,329	1,428	1,499
	GDP	[billion $]	11,101	14,577	17,794	25,876	34,234
India	Population	[million]	1,368	1,452	1,513	1,605	1,659
	GDP	[billion $]	10,816	17,084	22,652	37,966	54,074
China	Population	[million]	1,427	1,447	1,450	1,426	1,374
	GDP	[billion $]	26,889	37,997	47,427	64,986	84,825
OECD Pacific	Population	[million]	208	208	208	204	198
	GDP	[billion $]	8,761	9,644	10,407	11,842	13,081
	Population	[million]	7,713	8,185	8,551	9,210	9,772
	GDP	[billion $]	132,339	166,230	196,516	266,263	346,656

Although (battery) electric mobility has recently surged considerably, it has done so from a very low base, which is why, in terms of total numbers, electricity still plays a relatively minor role as an energy carrier in the transport sector.

Apart from their impacts on climate, increasing transport levels, especially of cars, trucks, and airplanes, also have unwanted side-effects: Accidents, traffic jams, the emission of noise and other pollutants, visual pollution, and the disruption of landscapes by the large-scale build-up of the transport infrastructure. However, road, rail, sea, and air transport are also an integral part of our globalized and interconnected world, and guarantee prosperity and inter-cultural exchange. Therefore, if we are to cater to people's desire for mobility while keeping the economy running and meeting the Paris climate goals, fundamental technical, operational, and behavioral measures are required immediately.

In this analysis, we discuss potential transport activity pathways and technological developments by which the requirement that warming does not exceed pre-industrial levels by more than 2.0°C or 1.5°C can be met—while at the same time maintaining a reasonable standard of mobility. For our transport scenario modeling, the global warming limits of 2.0°C and 1.5°C were translated into transport CO2 budgets. The scenarios in this analysis are based on global and regional scenarios developed by the German Aerospace Centre (DLR) published in February 2019 (J.Pagenkopf et.al. 2019). The methodology has been altered to reflect the requirements of the TUMI/GIZ transport initiative and the data and assumptions have been updated to reflect the developments of the global transport sector – especially the impact of the pandemic. Furthermore, the publication of the IPCC assessment report (AR6) in August 2021 (IPCC 2021)[33] identified a new carbon budget for 1.5˚C and 2.0˚C scenarios.

We structured our scenario designs around the following key CO2-reducing measures:

- Powertrain electrification;
- Enhancement of energy efficiency through technological development;
- Use of bio-based and synthetically produced fuels;
- Modal shifts (from high to low-energy intensity modes) and overall reductions in transport activity in energy-intensive transport modes.

The world final energy demand in the transport sector totaled 103[34] EJ in 2019, according to the IEA Energy Balances (IEA 2020)[35]. Based on this estimate, freight and passenger transport demand was estimated (see Chapter 3) with statistical data and energy efficiency figures.

Figure 15 shows that road passenger transport had the biggest transport final energy share of 53% in 2019. Most of this comprised individual road passenger modes (mostly cars, but also two- and three-wheel vehicles), which accounted for around 40% of all end energy in the transport sector. In total, road transport (passenger and freight) accounted for around 76% of total final energy demand for transport.

The majority of all passenger transport – in regard to the overall kilometers – is traveled by road. International freight transport however, is more dominated by rail and shipping with 45% of all ton-kilometers. Due to the high efficiency, the share of energy consumed by rail and shipping from global transport energy demand is small in relation to the share of global tonnage transported.

Figure 16 shows the passenger kilometer and freight transport ton-kilometer by transport mode in 2019 (OECD 2021)[36]. Road transport clearly dominates. International freight however, often arrives by ship and is further transported via rail and/or road.

OECD America and OECD Europe together make up half the total energy demand as shown in Figure 17. China is at nearly the same level as OECD Europe, though it has about twice as many inhabitants as OECD Europe.

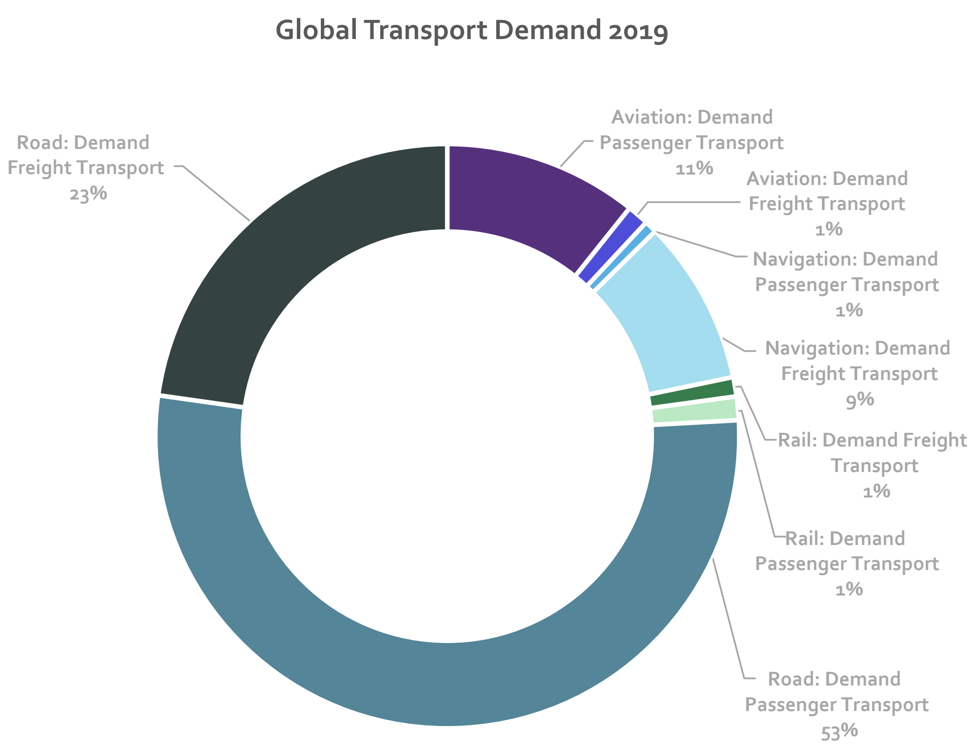

Figure 15. World final energy use by transport mode in 2019 (without international aviation or navigation bunker fuels)

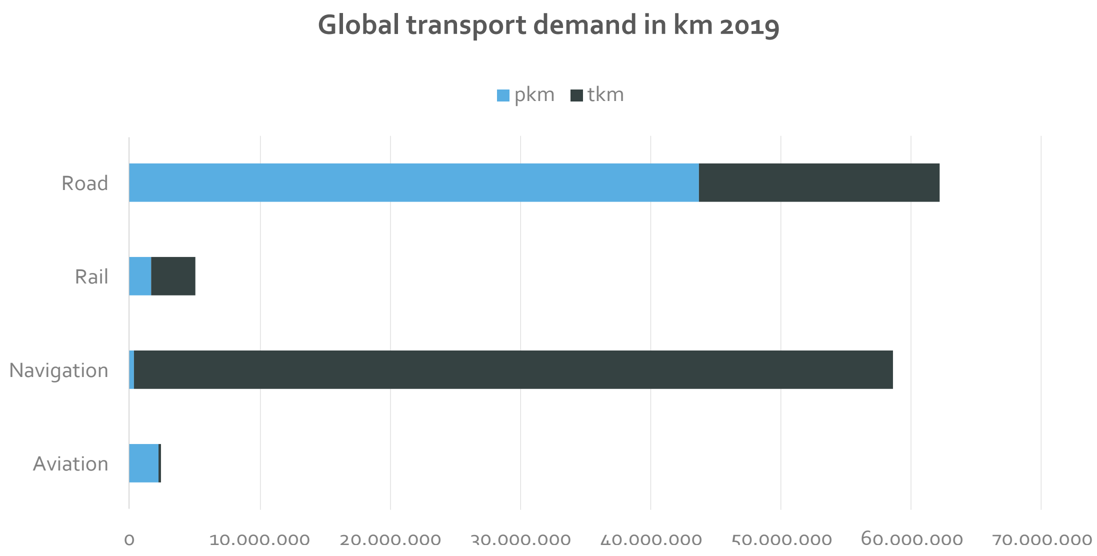

Figure 16. Transport mode performances of road, rail, navigation and aviation

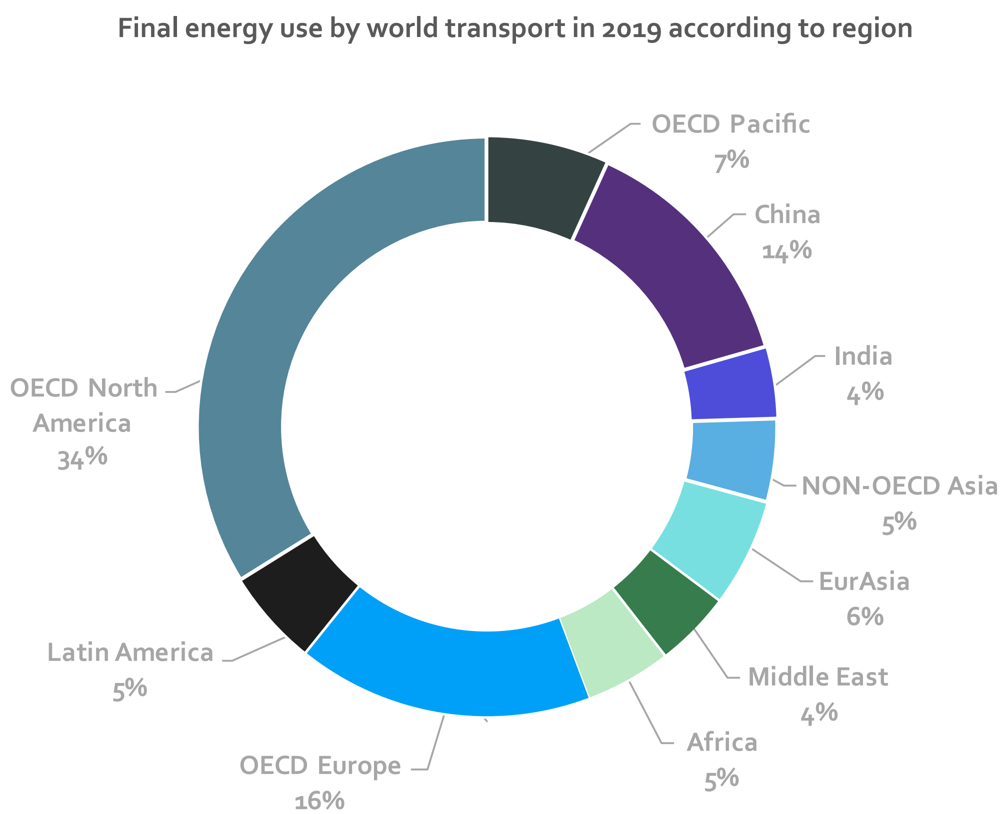

Figure 17. Final energy use by world transport in 2019 according to region

5.3. Global transport technologies - status quo 2020

Figure 18 shows the powertrain split of all transport modes in 2019 (by pkm or tkm) (IEA 2020) . With a few exceptions, the majority of modes were still heavily dependent on conventional internal combustion engines (ICE). A small number of buses had electric powertrains, which were mainly trolleybuses and increasingly also battery-powered electric buses, predominantly in China. China also has a particularly large number of electric two- and three-wheel vehicles. Almost all battery electric scooters worldwide were in China. Passenger rail was electrified to a large extent (e.g., metro and high-speed trains), whereas freight trains were predominantly not electrified.

5.4. Measures to reduce and decarbonize transport energy consumption

A variety of actions will be required so that the transport sector can conform to the 2.0°C or 1.5°C global warming pathways. The set of actions described can be clustered into technical and operational measures (e.g. energy efficiency increases, drivetrain electrification); behavioral measures (e.g., shifts to less-carbon-intensive transport carriers and an overall reduction in transport activity); and accompanying policy measures (e.g., taxation, regulations, urban planning, and the promotion of less-harmful transport modes). This study focuses on the 2.0°C and 1.5°C Scenarios and sets out the differences between these scenarios and the reference case.

Urgent and profound measures must be taken because the emissions reduction window will soon close. Temporary reductions in fossil-fuel-related transport activities (in terms of pkm and tkm of passenger cars, trucks, and aviation) in OECD countries seem nearly unavoidable until the electrification (based on renewable energy production) of the transport sector undergoes a breakthrough.

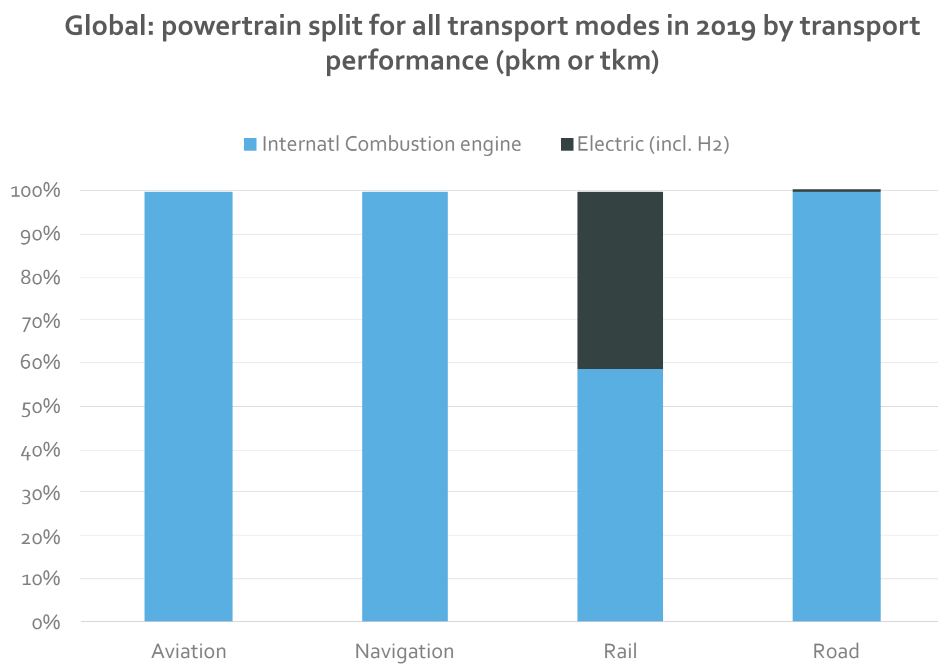

Figure 18. Powertrain split for all transport modes in 2019 by transport performance (pkm or tkm)

5.4.1. Powertrain electrification

Increasing the market penetration of highly efficient (battery and fuel-cell) electric vehicles, coupled with clean electricity generation, is a powerful lever and probably also the most effective means of moving toward a decarbonized transport system.

All electric vehicles have the highest efficiency levels of all the drivetrain options. Today, only a few countries have significant proportions of electric vehicles in their fleets. The total numbers of electric vehicles, particularly in road transport, are insignificant, but because road transport is by far the largest CO2 emitter in overall transport, it offers a very powerful lever for decarbonization.

In terms of drivetrain electrification, we cluster the world regions into three groups, according to the diffusion theory (Rogers 2003)[28]:

- Innovators: OECD North America (excluding Mexico), OECD Europe, OECD Pacific, and China
- Moderate: Mexico, Non-OECD Asia, India, Eurasia, and Latin America
- Late adopters: Africa and the Middle East.

Although this clustering is rough, it sufficiently mirrors the basic tendencies implemented in our scenarios. The regions differ in the speed with which novel technologies, especially electric drivetrains, will penetrate the market.

5.4.2. Mode-specific efficiency and improvements over time

In passenger transport, trains and buses are much more energy efficient per pkm than passenger cars or aeroplanes. This situation does not change fundamentally if only electric drivetrains are compared (Figure 19). It is apparent that railways and especially ships are clearly more energy efficient than trucks in transporting freight (Figure 20). The efficiency data are based on both literature-reported and on transport operator information documents in this report and in Pagenkopf et.al 2019. The efficiency levels in terms of pkm or tkm depend to a large extent on the underlying capacity utilization of the vehicles, which varies based on the world region. The numbers are average values and differences are evaluated at the regional level. For more details, see Table 17, Table 18 and Table 19. In addition to powertrain electrification, there are other potential improvements in energy efficiency and their implementation will steadily improve energy intensity over time. Regardless of the types of powertrains and fuels used, efficiency improvements on the MJ/pkm or MJ/tkm level will result from (for example):

- Reductions in powertrain losses through more-efficient motors, gears, power electronics, etc.;
- Reductions in aerodynamic drag;
- Reductions in vehicle mass through light-weighting;
- The use of smaller vehicles;
- Operational improvements (e.g., through automatic train operation, load factor improvements).

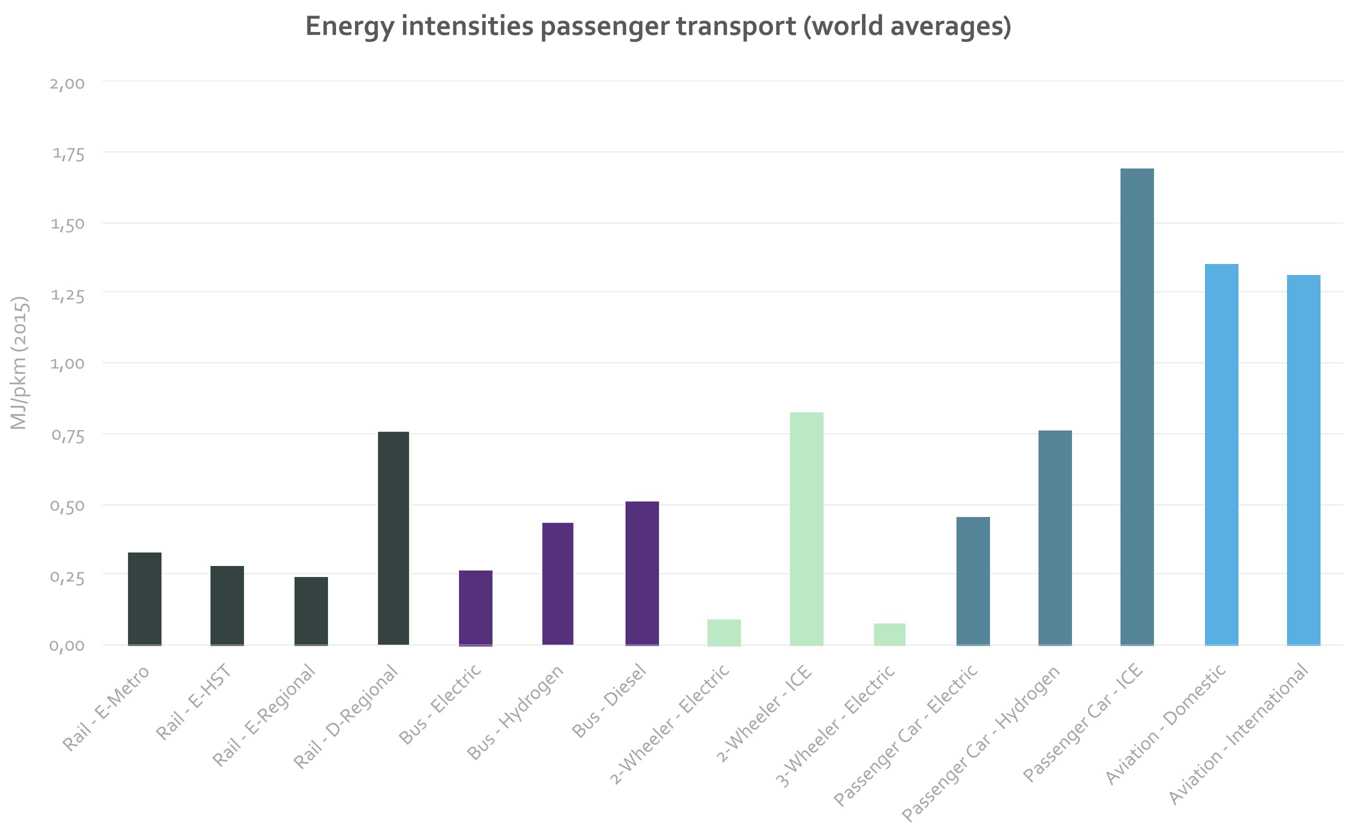

Figure 19. Energy intensities urban and inter-urban passenger transport modes in 2019 (world averages) (Source: DLR IFFT 2019[39])

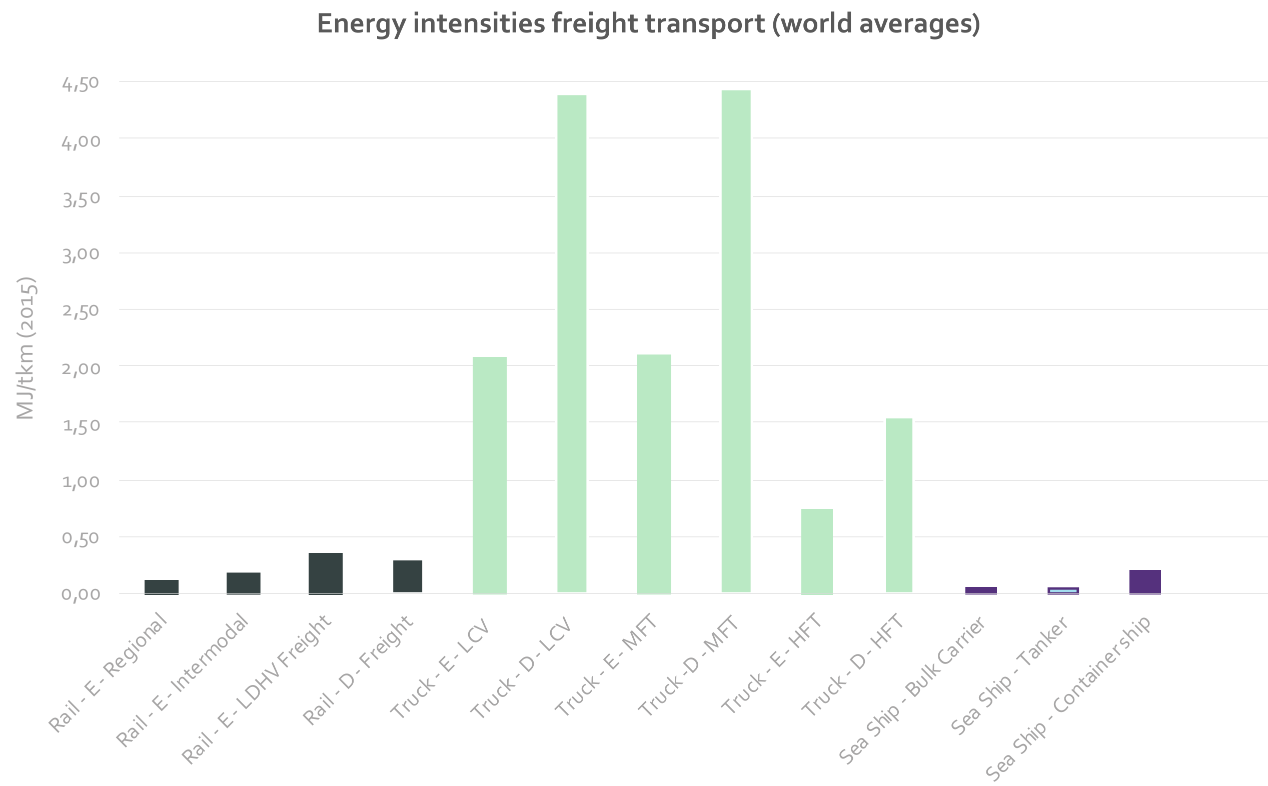

Figure 20. Energy intensities in freight transport modes in 2019 (world averages) (Source: DLR IFFT 2019)

5.5. Scenario Narratives

Three scenarios have been calculated: The reference case is based on the IEA World Energy Outlook 2020 Stated Policies scenario and two pathways which limit energy-related carbon emissions from the transport sector within the carbon budget for 2.0˚C and 1.5˚C (67% likelihood) according to the IPCC AR6 carbon budget. The carbon budget for transport takes other sectors into account (see Methodology, Chapter 2). All three scenarios are not forecasts but projections under different assumptions. Details of the assumptions for all scenarios are described in the following section.

5.5.1. REFERENCE case

The 'REFERENCE' case is based on the IEA Stated Policies Scenario (IEA 2020)[40] until 2040, with extrapolation to 2050. The scenario narrative assumes that that there will be no major changes in the global transport sector across all transport modes. Electrification of road transport remains on a relatively low level and no major shift from individual to public transport and energy-less mobility forms (cycling and walking) will take place. The growth in the share of the commercial road vehicle fleet and of the fleet of two- and three-wheel vehicles with electric powertrains will be small, as will the increase in further rail electrification. Aviation and navigation (shipping) will remain fully dependent on conventional kerosene and diesel, respectively. The results of the Reference case are within the same order of magnitude as the IEA scenario but does not claim to model all results exactly.

5.5.2. The 2.0°C Scenario

The 2.0˚C Scenario will remain with a cumulative carbon budget of 130 Gt CO_2 between 2020 and 2050 for the global transport sector. Based on the low market share of BEV observed today (2020), minimal progress in electrification until 2025 is assumed in the 2.0°C Scenario. Moving towards 2030, the innovative regions will experience strong electrification, encouraged by purchase incentives, carbon pricing, EV credit systems, and tightened CO_2 fleet emission targets. OECD will take the lead in the implementation of electric mobility and other transport services leading to the decarbonization of the entire sector.
Furthermore, it is assumed that supportive policy measures which encourage energy efficiency, electrification, and the use of public transport are implemented by 2030.

5.5.3. The 1.5°C Scenario

The 1.5˚C Scenario will remain with a global cumulative carbon budget of 110 Gt CO2 until 2050 and assumes the same technical and behavioral change measures as the 2.0˚C scenario, but implementation will be faster. In the 1.5°C Scenario, an earlier and more rapid ramp-up of electric powertrain penetration is required than in the 2.0°C Scenario and the innovative regions will be at the forefront. The moderate regions will also need to electrify more rapidly than in the 2.0°C Scenario but will end up with only a minimally higher share by 2050. Supportive policy measures which encourage energy efficiency, electrification, and the use of public transport must be implemented by 2025 and remain in place until the end of the scenario period. Furthermore, non-technical measures are required to reduce transport demand further than under the 2.0˚C. 'Active mobility' policies that encourage cycling and walking as well as measures that reduce the need for long commutes to work are needed to achieve the demand reduction.

6. Key Results: Global and regional transport scenarios

This chapter provides an overview about the key assumptions and results for the REREFENCE case and the 2.0°C and 1.5°C scenario as described in Chapter 4. The regional breakdown is based on the IEA world regions (Table 21).
The demand projections are based on changing needs for passenger kilometers and transported freight in ton-kilometers over time (2020 to 2050) and are assumptions. Based on this, the required transport service – and therefore the actual energy demand – has been calculated with vehicle specific energy intensities. The energy demand in PJ and the resulting carbon dioxide emissions are calculated results.

6.1. Global

The global transport demand is a sum of the 10 world regions plus the bunker fuels under three scenarios. Bunker fuels are all fuels required for inter-regional aviation and shipping transport and therefore not part of the regional demand.

6.1.1. Development of transport demand

The assumed development for all three scenarios is based on the same population and economic developments in $GDP. The overall passenger transport demand doubles under the global reference case while the 2.0°C Scenario decreases demand by almost 20%. The 1.5°C Scenario assumes a slightly lower demand and global passenger transport will be 30% lower than in 2020. Global freight demand increases in all scenarios; the Reference case demand will increase by over 80% by 2050, while the 1.5°C limits growth to plus 30%.

The key requirements for achieving the reduction of transport energy demand in the alternative scenarios follow a three-step approach:

- Reduce transport kilometers from passengers and freight with behavior change, urban planning, increased local production and transport logistics;
- Shift to more energy efficient transport modes e.g. from road to rail for passengers and from aviation to navigation for freight;
- Innovate – replace inefficient combustion engines with efficient electric drives.

Table 21. World regions used in the scenarios

World region	Countries
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Israel, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
OECD North America	Canada, Mexico, United States of America
OECD Pacific	Australia, Japan, Korea (South), New Zealand
Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Kosovo, Kyrgyz Republic, Latvia, Lithuania, Montenegro, Romania, Russia, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, Gibraltar and Malta
China	People's Republic of China, including Hong Kong
India	India
Non-OECD Asia (without China and India)	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Chinese Taipei, Cook Islands, East Timor, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Macao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Tonga, Vanuatu, Vietnam,
Latin America	Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, Saint Lucia, St. Pierre et Miquelon, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, , Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, Zimbabwe
Middle East	Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

Table 22. Global: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	123%	157%	182%	191%	201%
	2.0°C	100%	114%	132%	215%	274%	350%
	1.5°C	100%	117%	136%	221%	282%	360%
Road	REF	100%	117%	129%	161%	183%	209%
	2.0°C	100%	108%	113%	108%	100%	95%
	1.5°C	100%	112%	109%	105%	100%	94%
Domestic aviation	REF	100%	172%	224%	256%	270%	282%
	2.0°C	100%	101%	96%	87%	83%	79%
	1.5°C	100%	101%	96%	71%	58%	47%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	102%	97%	87%	83%	79%
	1.5°C	100%	101%	94%	81%	75%	69%
Total	REF	100%	119%	134%	166%	186%	211%
	2.0°C	100%	108%	113%	111%	105%	103%
	1.5°C	100%	111%	109%	108%	105%	101%

Table 23. Global: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	146%	178%	197%	217%
	2.0°C	100%	110%	138%	224%	286%	365%
	1.5°C	100%	133%	186%	238%	269%	305%
Road	REF	100%	145%	160%	195%	215%	237%
	2.0°C	100%	108%	113%	103%	98%	95%
	1.5°C	100%	110%	107%	103%	98%	92%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	76%	65%	51%
Domestic navigation	REF	100%	106%	112%	123%	130%	136%
	2.0°C	100%	105%	99%	90%	86%	81%
	1.5°C	100%	103%	97%	85%	80%	75%
Total	REF	100%	115%	124%	142%	152%	163%
	2.0°C	100%	106%	104%	99%	97%	97%
	1.5°C	100%	106%	103%	96%	92%	89%

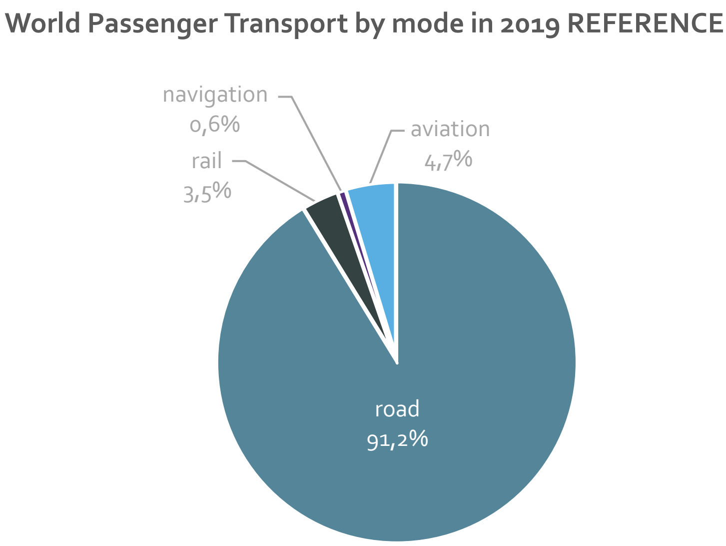

Figure 21. Global: Passenger transport shares by mode in 2019

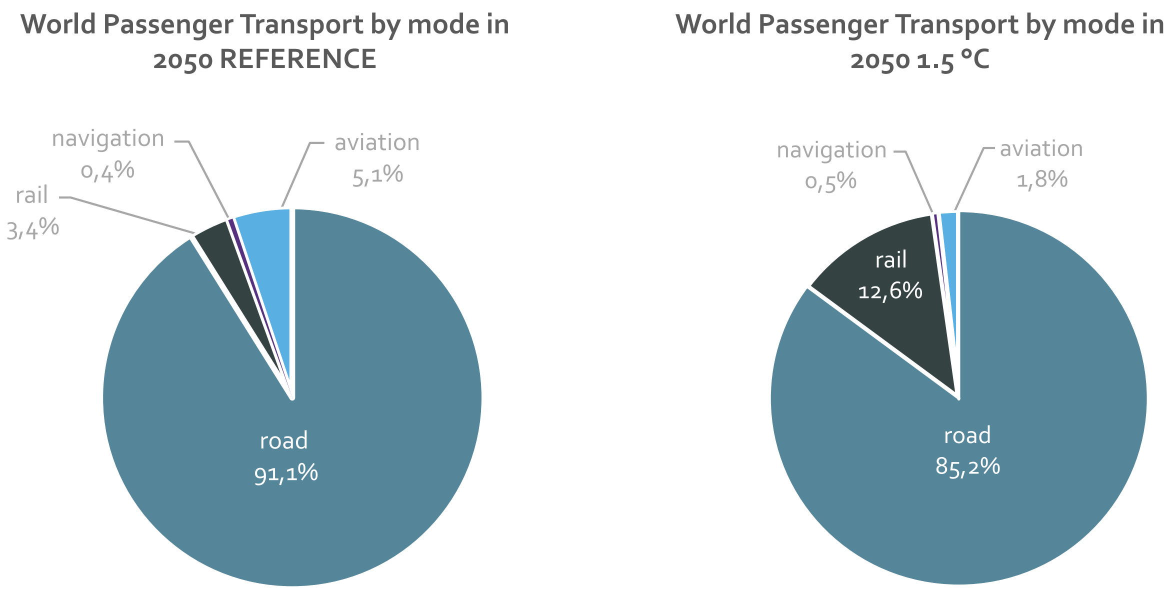

Figure 22. Global: Development of passenger transport under two scenarios by mode by 2050

In 2019, road transport was dominant over all other transport modes with almost 91% of all passenger kilometers traveled via some form of road vehicles globally. Based on traveled kilometers, just over 3.5% of journeys were by train and around 5% by plane. While ship transport is one of the most important means of transport for freight, marine-based passenger transport has only a very minor contribution on the global level. In order to implement the 1.5°C Scenario, passenger transport needs to shift from road to rail. Efficient lightrail in cities, commuter trains for short to medium distances and high speed trains that offer convenient services and therefore an alternative to individual car journeys.

While the shares of transport modes vary significantly by region, the overall proportions are roughly the same across all regions and even across all scenarios (Figure 23).

Urban transport will significantly reduce road transport via cars and shift to public transport either to other road vehicles such as buses, or trains. Furthermore, the role of electric bikes and walking will have to increase under the 1.5°C Scenario as well. However, road transport will remain dominant with well over 80% (Figure 24) until 2050. Therefore, the modal shift within road transport systems – such as from individual cars to public transport, cycling or mobility services such as car sharing – are of very high importance.

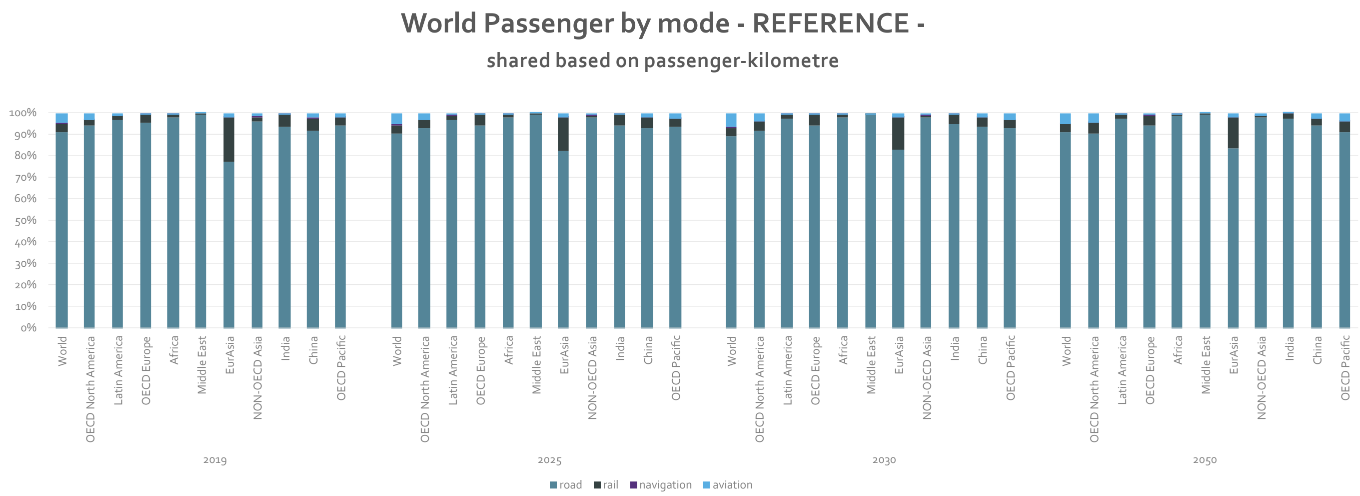

Figure 23. World Passenger Transport by mode -REFERENCE- shares based on passenger-kilometre-

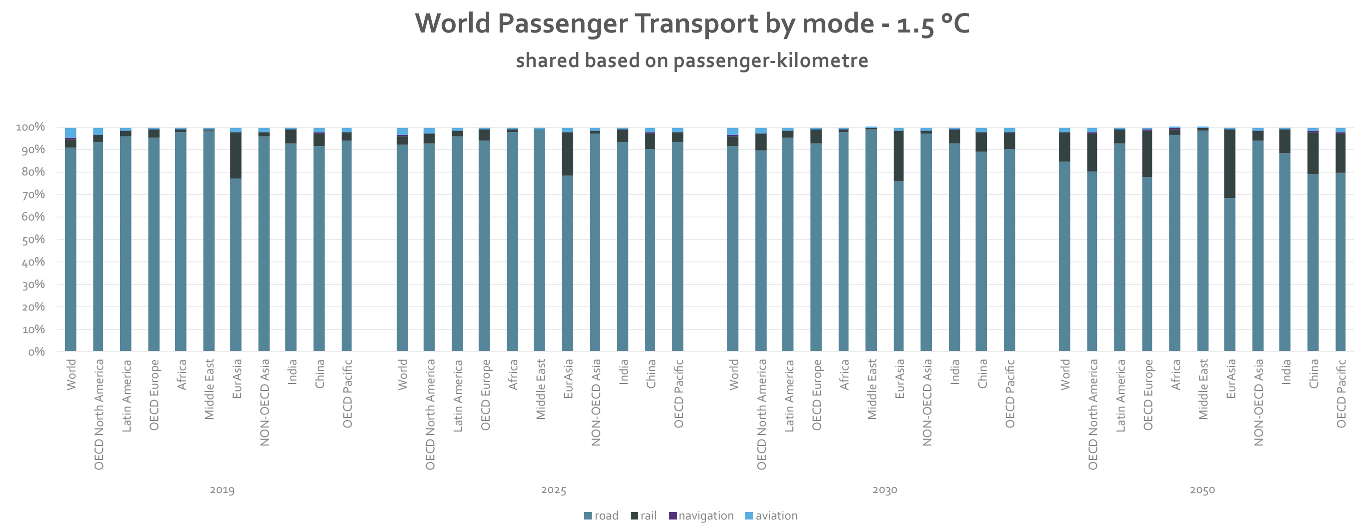

Figure 24. World Passenger Transport by mode -1.5˚C case- shares based on passenger-kilometre-

Maritime shipping is the backbone of world trade; it is estimated that some 80% of all goods are carried by sea. In terms of value, global maritime container trade is estimated to account for around 60% of all seaborne trade, which was valued at around 14 trillion U.S. dollars in 2019 (Statista 2021)[41].

Aviation – in regards to tonnage – plays a comparatively minor role globally. In regard to ton-kilometer, road transport is dominating globally: Every second ton is transport via road and only 10% via rail (Figure 25). However, the different transport modes cannot be separated as goods delivered by ship are further distributed via road and rail. Thus, a modular shift is often not directly possible. Ship transport cannot by replaced by trains in most cases and vice versa. There is a competition between road and rail and modular shifts in favor of rail freight transport. The 1.5˚C pathway assumes that about one-third of the freight transported via trucks are shifted to rail transport systems, while the Reference Scenario assumes that domestic (inland and coastal) navigation will lose both to rail and road transport systems (Figure 26).

In comparison to passenger transport, freight transport is far more diverse and regional differences are significant. In Eurasia, a region to a large extent similar to the former USSR, rail transport shoulders about half of all freight transports in regard to tonnage. This reflects the significance of the trans-Siberian railway line connecting the European part of Russia with Mongolia (Ulan Bator) and China (Beijing).

In Non-OECD Asia, navigation transport is by far the most important transport mode, which reflects the situation of the island states Indonesia and the Philippines as well as the vast coastlines of Southeast Asian countries.

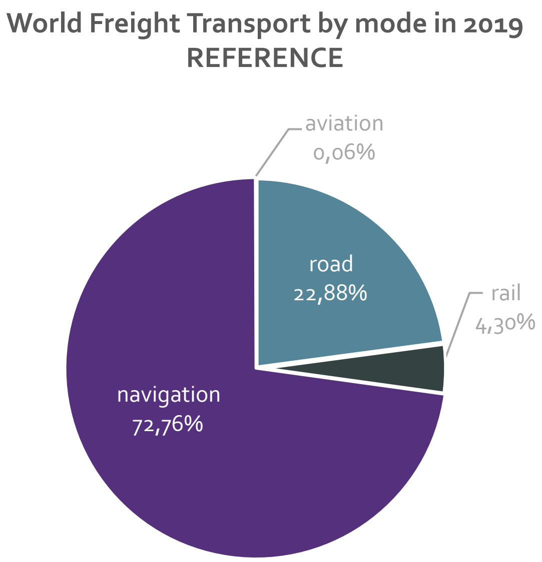

Figure 25. Global: Freight transport by mode in 2019

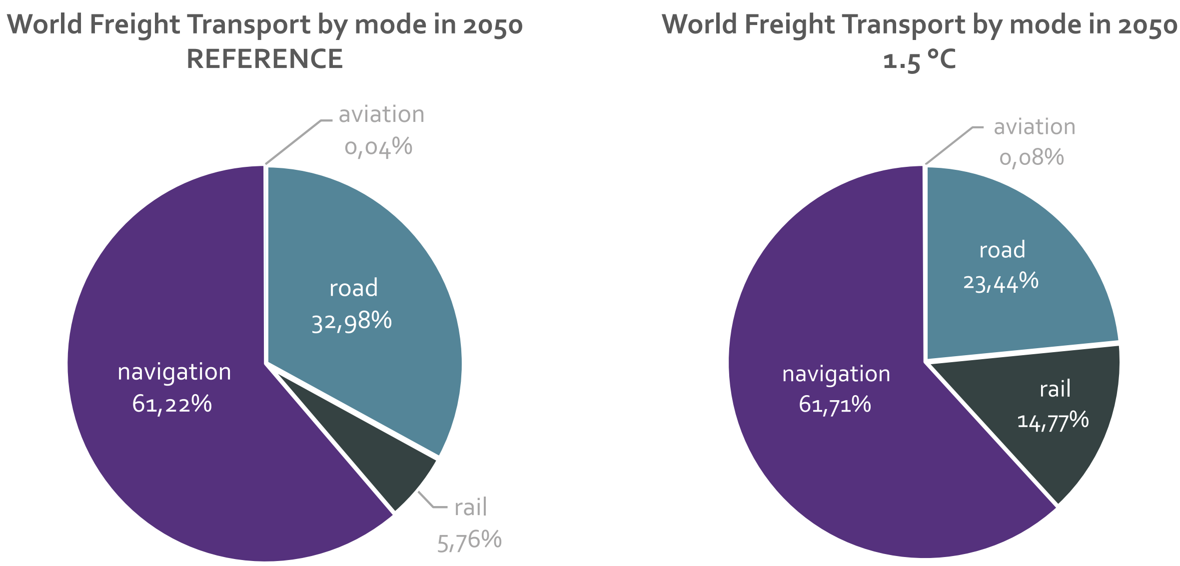

Figure 26. Global: Development of freight transport under two scenarios by mode by 2050

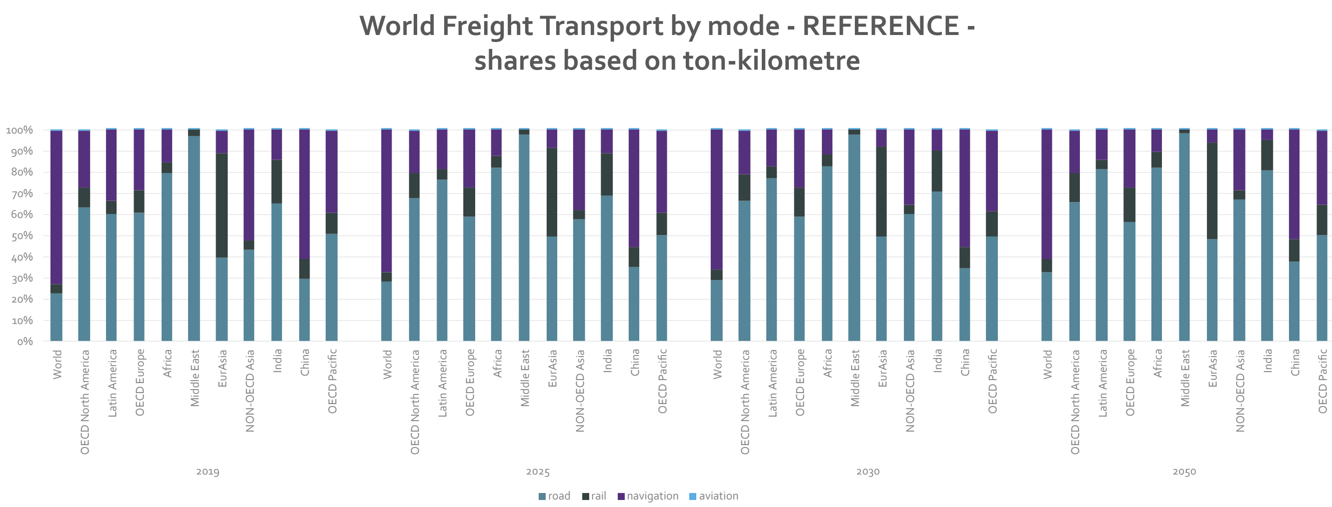

Figure 27. World: Freight Transport by mode -REFERENCE- shares based on ton-kilometre-

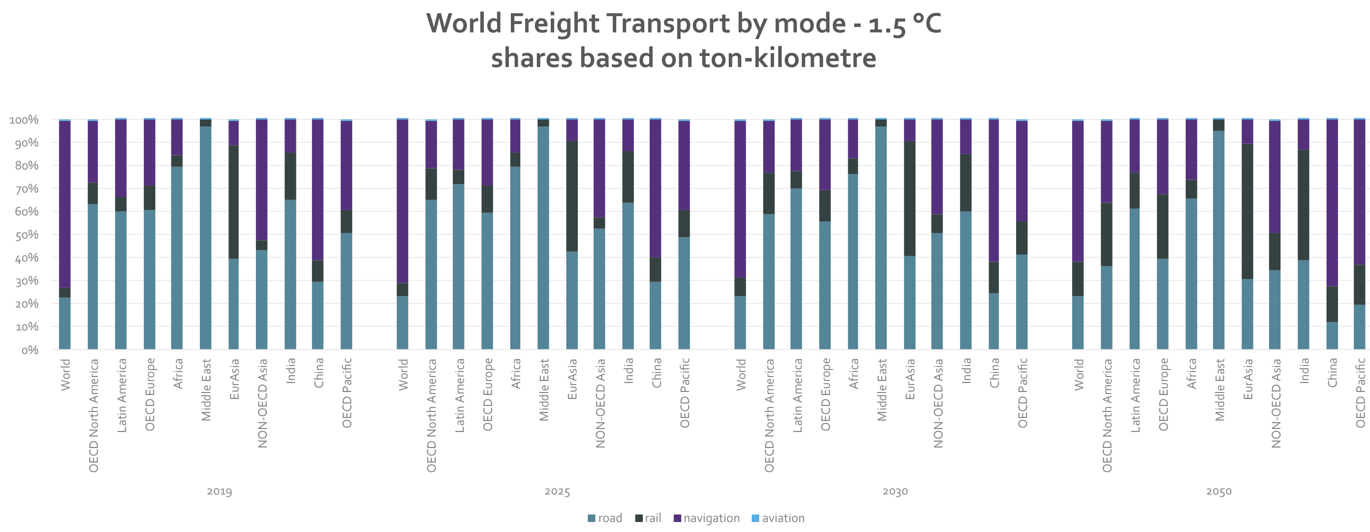

Figure 28. World: Freight Transport by mode -1.5˚C case- shares based on ton-kilometre-

6.1.2 Development of transport services

A key target for the global transport sector is the introduction of incentives for people to drive smaller cars and use new, more efficient vehicle concepts. In addition, it is vital to shift transport use to efficient modes like rail, light rail, and buses, especially in the expanding large metropolitan areas. Furthermore, the 2.0˚C and the 1.5˚C Scenarios cannot be implemented without behavioral change: It is not enough to simply exchange vehicle technologies but to reduce the transport need in regard to the traveled kilometers and to increase 'non-energy' travel-modes such as cycling and walking.

Along with rising prices for fossil fuels, these changes reduce the further growth in car sales projected under the Reference Scenario. Due to population increases, GDP growth, and higher living standards, energy demand from the transport sector is expected to increase in the Reference Scenario by around 4% to 30,520 PJ/a in 2050. In the 2.0˚C scenario, efficiency measures, modal shifts, and the mentioned behaviour changes can reverse the trend compared to the Reference case and reduce the energy demand by about 60% by 2050. Additional modal shifts and technology switches lead to slightly higher energy savings in the 1.5°C scenario.

Highly efficient drives – with a focus on electric mobility – supplied with renewable will result in large efficiency gains. By 2030, electricity will provide 9% of the transport sector's total energy demand in the 2.0°C Scenario, while in 2050, the share will be 56% (58% in the 1.5°C Scenario). Hydrogen and other synthetic fuels generated using renewable electricity are complementary options to further increase the renewable share in the transport sector. In 2050, up to 1,400 PJ/a of hydrogen is used in the transport sector for the 1.5°C Scenario.

Development of passenger vehicle drives

All Passenger cars and light commercial vehicles in use are projected to achieve battery-electric-vehicle (BEV) shares of between 8% and 15% by 2030. This will require a massive build-up of battery production capacity in the coming years. New car sales will already be dominated by battery electric passenger vehicles under the 1.5˚C in 2030. However, with an assumed average lifetime of 15 years for ICE passenger cars, the existing car fleet will still predominantly use internal combustion engines. Under the assumption that new ICE passenger cars and buses will not be produced after 2030, BEV will dominate the passenger vehicle fleet of 2050 under the 1.5˚C scenario. OECD countries and China are assumed to lead the development of BEV and therefore have the highest shares, while Africa and Latin America are expected to have the lowest BEV shares. Fuel cell-powered passenger vehicles are projected to play a significantly smaller role than battery electric vehicles and will only be used for larger vehicles such as SUVs and buses.

Electrification of trains

The share of electric trains and diesel-powered locomotives varies significantly by region (Figure 30). Under the 1.5˚C Scenario, all diesel locomotives are phased out by 2050 in all regions. It is assumed that bio and synthetic fuels as well as hydrogen will play a minor role and that around 90% of all trains – both for passenger and freight transport – will use electric locomotives. The highest utilization rates of diesel locomotives in 2019 are in the Middle East (98%) and in OECD North America (95%), while the majority of trains in Europe are electrified.

Table 24. Global: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	2,872	2,671	2,721	2,777	2,860	3,228
	2.0°C	2,872	2,671	2,495	2,215	2,887	3,881
	1.5°C	2,872	2,671	2,563	2,628	2,758	3,532
Road	REF	91,900	84,033	84,772	87,098	102,278	124,718
	2.0°C	91,900	84,033	71,602	68,718	44,497	30,922
	1.5°C	91,900	84,033	72,854	59,132	34,681	26,947
Domestic aviation	REF	14,449	10,695	14,735	17,826	19,350	20,807
	2.0°C	14,449	10,695	9,106	8,088	6,957	6,088
	1.5°C	14,449	10,695	9,106	8,088	5,686	3,698
Domestic navigation	REF	11,913	11,072	11,461	11,853	12,647	13,617
	2.0°C	11,913	11,072	11,294	10,569	9,246	8,151
	1.5°C	11,913	11,072	11,132	10,277	8,751	7,507
Total	REF	124,082	111,361	113,690	119,553	137,136	162,370
	2.0°C	124,082	111,361	94,496	89,590	63,587	49,042
	1.5°C	124,082	111,361	95,655	80,125	51,876	41,684

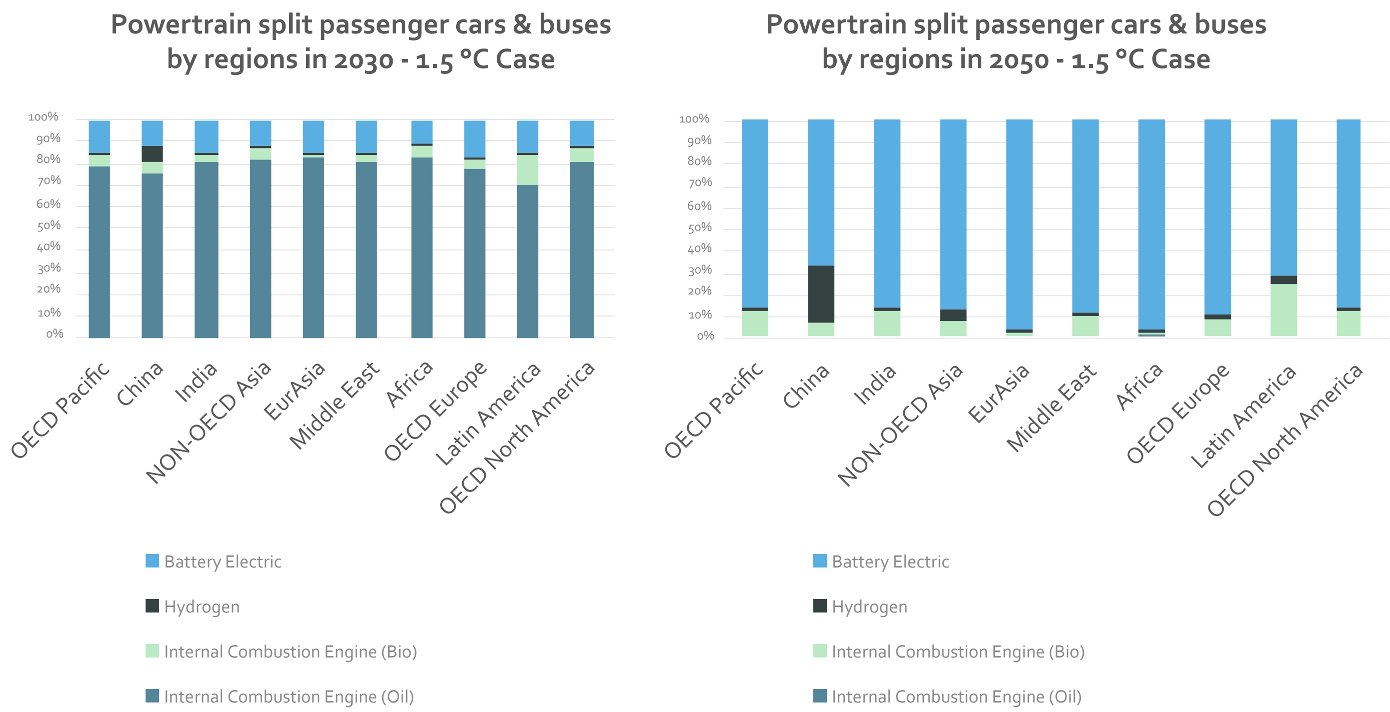

Figure 29. Powertrain split (fleet) passenger cars and busses by region in 2030 (left) and 2050 (right) - 1.5°C scenario

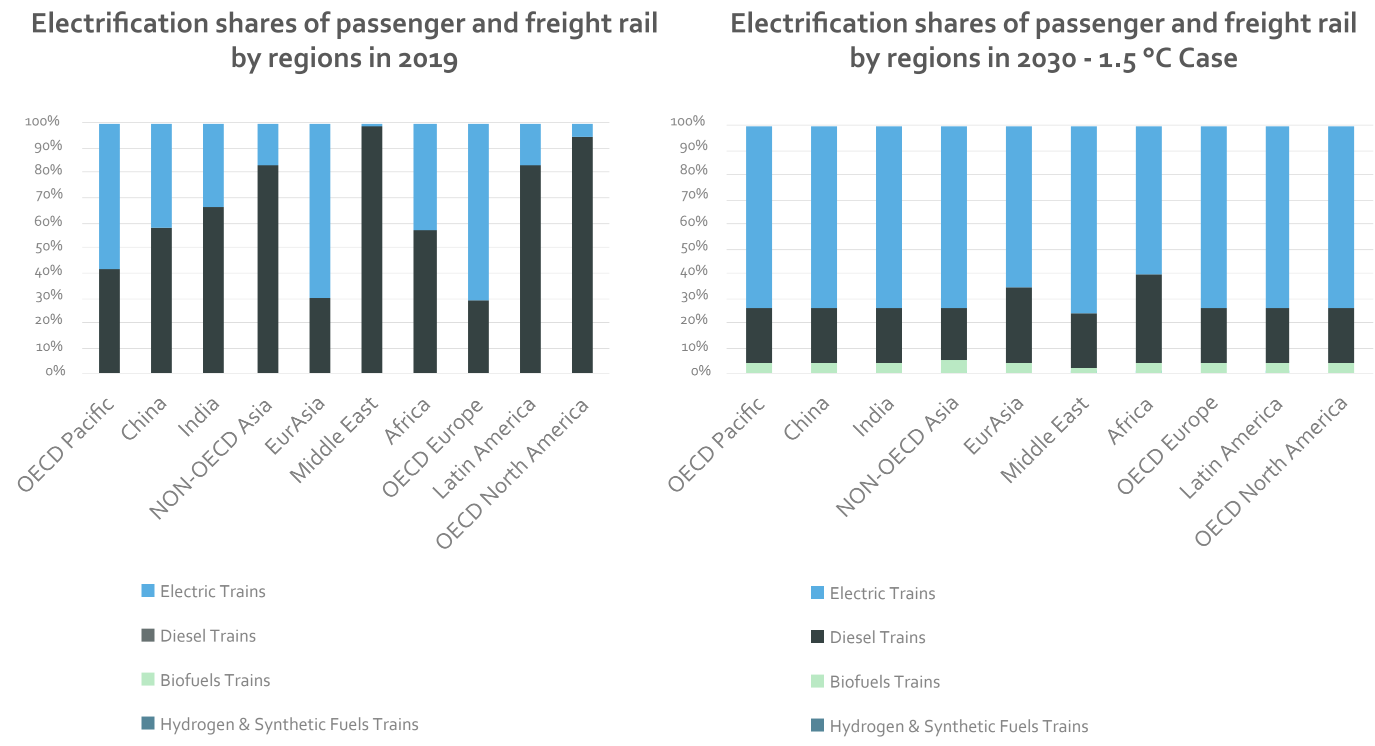

Figure 30. Electrification shares of passenger and freight rail in 2019 (left) and 2030 (right) - 1.5°C scenario

Shipping and Aviation: Dominated by combustion engines for decades to come

Navigation will probably remain predominantly powered by ICE in the next few decades. Therefore, we did not model the electrification of freight vessels. However, pilot projects using diesel hybrids, batteries, and fuel cells are in preparation (DNV GL 2015). We assumed the same increase in the share of bio- and synthetic fuels over time as in the road and rail sectors.

In aviation, energy efficiency can be improved by measures such as winglets, advanced composite-based lightweight structures, powertrain hybridization, and enhanced air traffic management systems (Madavan 2016; Vyas et al. 2013). We project a 1% annual increase in efficiency on a per pkm basis and a 1% annual increase in efficiency on a per passenger–km basis.

Aviation will probably remain predominantly powered by liquid fossil fuels (kerosene and bio- and synthetic fuel derivatives) in the medium- to long-term because of limitations in electrical energy storage. We project a moderate increase in domestic pkm flown in electric aircrafts starting in 2030, with larger shares in OECD Europe because the flight distances are shorter than, for example, in the USA or Australia. Norway has announced plans to perform all short-haul flights electrically by 2040 (Agency France-Presse 2018).

However, no real electrification breakthrough in aviation is foreseeable unless the attainable energy densities of batteries increase to 800–1000 Wh/kg, which would require fast-charging post-lithium battery chemistries.

That said, it is estimated that over 200 electric aircraft programs are in progress around the world (Downing 2019). While small electric planes (up to car size) are in the demonstration phase, long haul flights with electric planes are currently not viable with contemporary battery technology.

Form the technology innovation point of view, electric aviation is an important field of engineering and investment in this sector needs to occur now in order to achieve results for the mid-2030s. Domestic aviation – mainly short distance flights of up to around 700km – make up about 45% of all global flights (Downing 2019). The electrification of passenger planes for those distances will most likely start in this market segment.

This research however, has a focus on rapid carbon dioxide reduction in the global transport sector, and electric aviation realistically does not play a role in large amounts of carbon reduction before 2040. However, the development of this technology is important in the long-term.

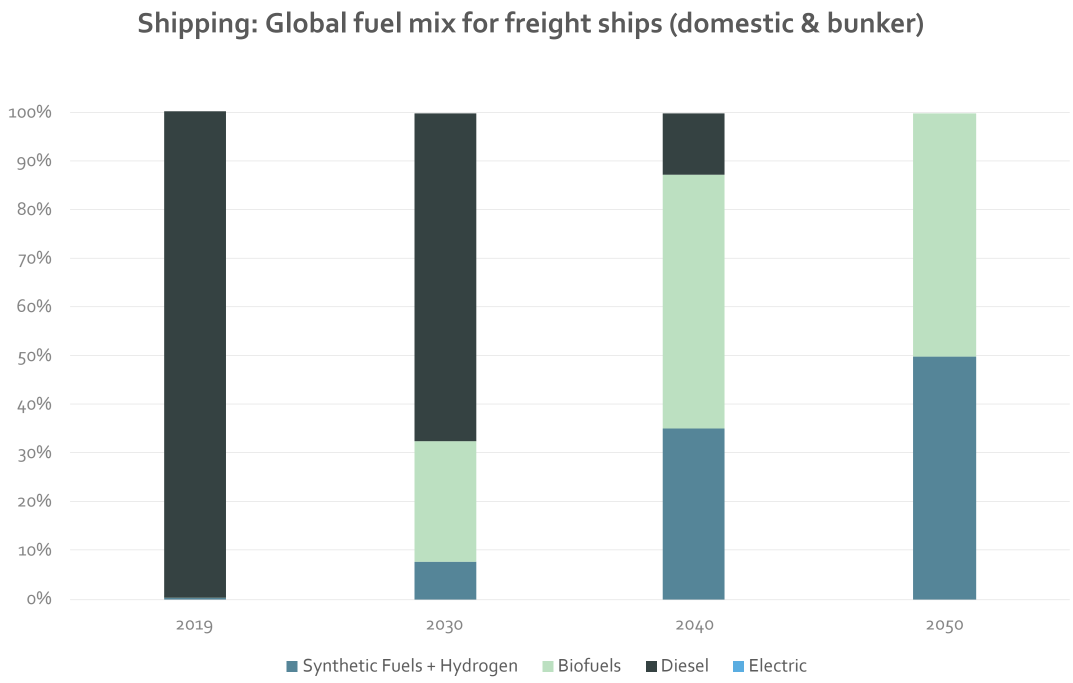

Figure 31. Shipping: Global fuel mix for freight ships (domestic & bunker)- 1.5°C scenario

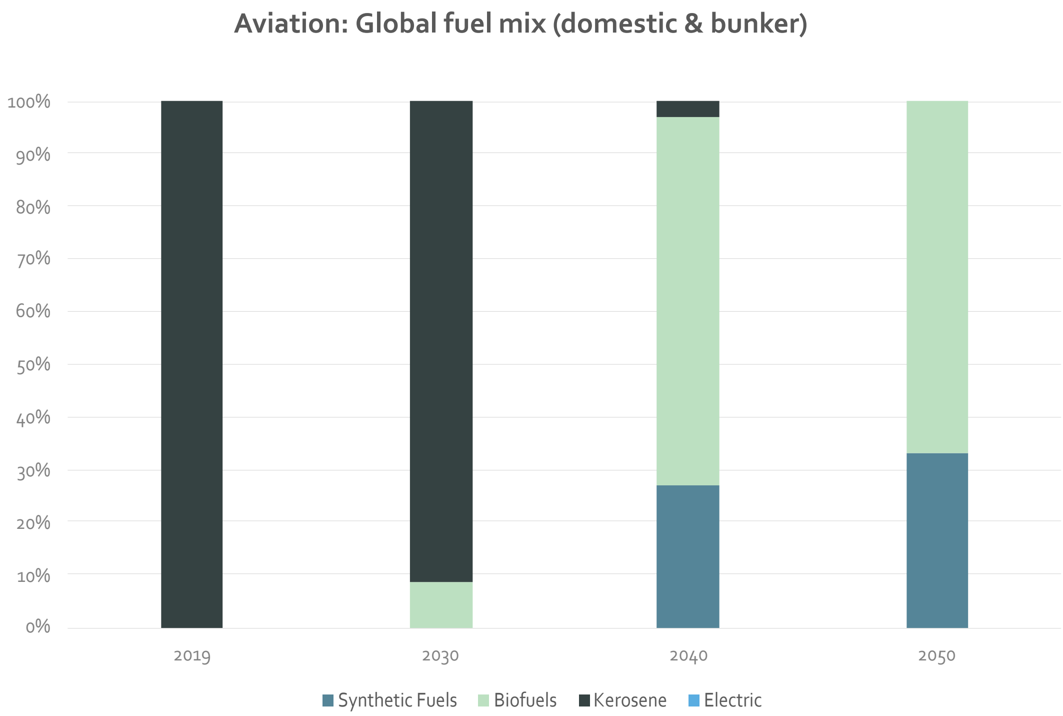

Figure 32. Electricity-performed pkm in aviation under the 1.5°C Scenario

Aviation: Global fuel mix (domestic & bunker)

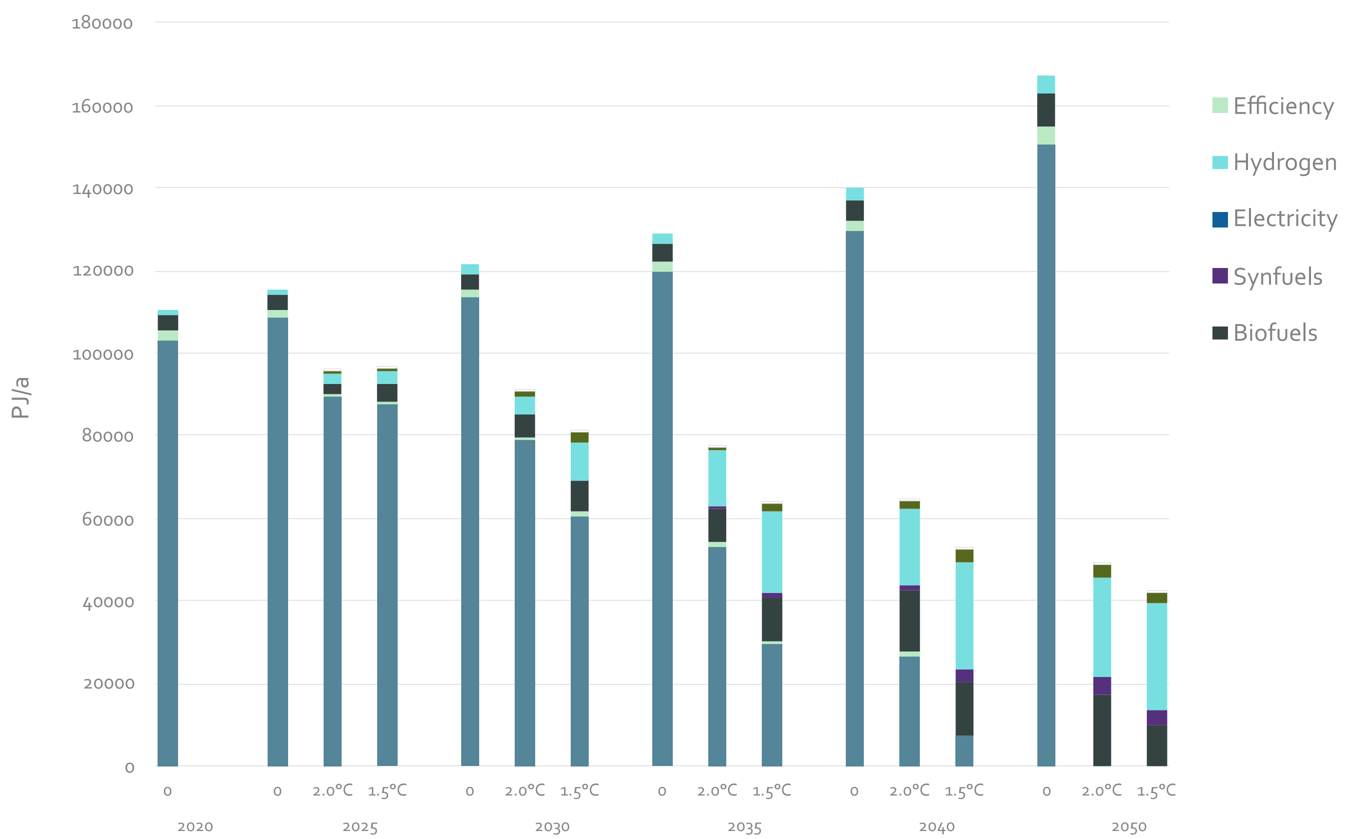

Figure 33. Global: Final energy consumption transport under three scenarios

Figure 33 shows the global final energy consumption for all transport modes under the Reference case and the 2.0˚C and 1.5˚C pathway. The significant drop in demand under the 2.0˚C and 1.5˚C scenarios is a result of a mixture of technical and lifestyle changes. The main factors include:

1. Electrification of the road and rail transport vehicles;
2. Increased efficiency and therefore less energy demand per kilometer especially for cars and freight transporter;
3. Decrease in individual road transport kilometers;
4. Increase in public transport solutions for both the road and the rail sector.

6.1.3. Carbon dioxide emission in the global transport sector

In a last step, the carbon dioxide emissions are calculated on the basis of the primary energy fuel demand for oil and gas and the total electricity demand in the transport sector. In regard to fossil fuels, the primary energy demand for each transport mode includes all losses. Therefore, CO_2 emission can be calculated via fixed emission factors; 75 ktCO_2 per PJ for oil and 56 ktCO_2 per PJ for gas. The ratio between e.g. one liter of burned crude oil and the resulting CO_2 emissions is constant and increased efficiencies from e.g. combustion engines will lead to a decreased oil demand for each kilometer, while the amount of CO_2 emitted for each liter of oil remains the same.

For the electricity demand of battery-electric vehicles, electric train, and the production of synthetic and hydrogen fuels with electricity, the CO_2 emissions are calculated with the regional CO_2 intensity for the year of calculation under the same scenario. Example: Electricity generation in OECD Europe in 2019 was 272 gCO_2 per kWh; this value will be used as the emission factor for each kilowatt-hour consumed in the transport sector. Under the 1.5˚C Scenario, the carbon intensity of electricity will decrease to 92gCO_2/kWh in 2030 and will be carbon-free by 2050.

Table 25 shows the annual CO_2 emission on million-tons by transport mode globally, while Figure 34 provides the share of the cumulative CO_2 emissions between 2020 and 2050.

Table 25. Global: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	295	269	199	165	111	114
	2.0°C	295	269	183	119	53	0
	1.5°C	295	269	186	137	23	0
Road	REF	7,298	6,686	6,374	6,355	7,206	8,505
	2.0°C	7,298	6,686	5,367	4,885	1,513	0
	1.5°C	7,298	6,686	5,482	3,955	659	0
Domestic aviation	REF	1,084	802	1,105	1,337	1,451	1,561
	2.0°C	1,084	802	686	589	318	0
	1.5°C	1,084	802	686	589	67	0
Domestic navigation	REF	896	833	860	889	948	1,020
	2.0°C	896	833	851	771	422	0
	1.5°C	896	833	839	687	160	0
Total	REF	9,573	8,590	8,538	8,746	9,716	11,200
	2.0°C	9,573	8,590	7,086	6,364	2,306	0
	1.5°C	9,573	8,590	7,193	5,369	909	0

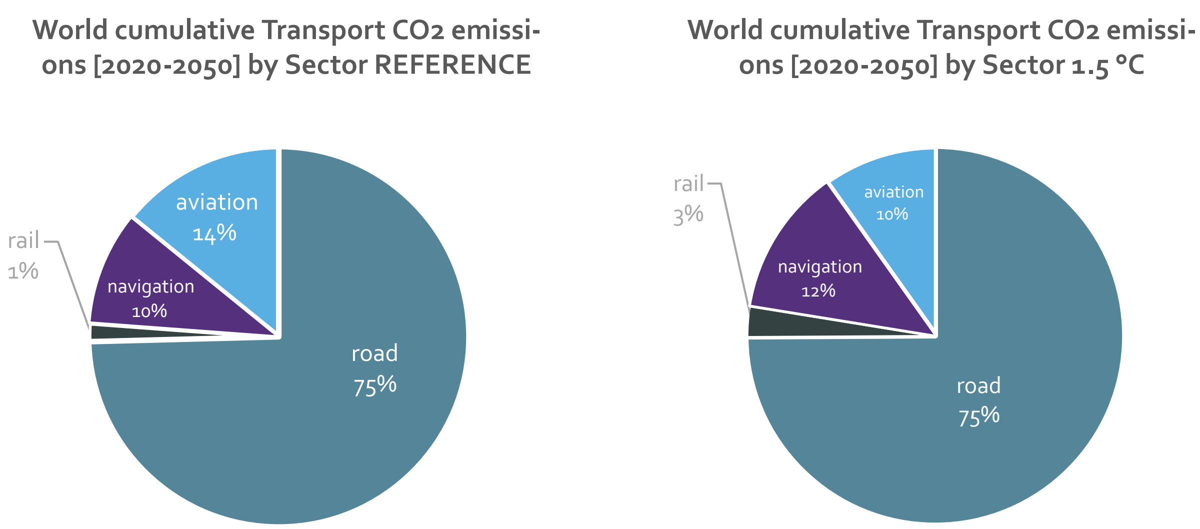

Figure 34. Global: Cumulative CO_2 Transport Emissions [2020-2050]

6.1.4. Carbon dioxide emissions in the transport sector – regional breakdown

Energy-related CO2 emissions within the transport sector varies significantly by region; OECD countries have by far the highest emissions, both in total and relative to the population in those countries. OECD North America would emit around 70 GtCO2 between 2020 and 2050 under the reference case – a pathway that assumes no major changes in the transport sector over the next 30 years.

In order for the global carbon budget to stay within a 67% change under 1.5˚C of 400 GtCO2 during the same time frame, the global transport sector under the Reference case development would consume 74% of the total budget, leaving only 26% for all other sectors such as buildings, food & agriculture, industrial production, and all other economic activities.

Under the Reference case, with around 15% of the global population, OECD North America, OECD Europe, and OECD Pacific's transport sector would take up 26% of the total carbon budget. Thus, the restructuring of the transport sector is without alternative.

Table 26 shows the regional cumulative CO2 emissions of the transport sector between 2020 and 2050. Under the 1.5˚C pathway, the transport sector will have about a quarter of the total carbon budget required to achieve the Paris Climate Agreement Goals. For China and India – representing just over 30% of the global population as projected for 2050 – the total emissions would add up to 20 Gt CO2 – about 5% of the total Paris Carbon Budget. However, under the Reference case, both countries would take up 15%.

Table 26. Regional cumulative carbon emissions between 2020 and 2050 under three scenarios

Cumulative energy-related CO_2 emissions of the transport sector by region - 2020 to 2050 [$GtCO_2$]			
	REFERENCE	2.0˚C	1.5˚C
OECD North America	63	34	31
Latin America	19	8	7
OECD Europe	27	15	13
Africa	15	6	5
Middle East	15	6	5
EurAsia	13	6	5
NON-OECD Asia	22	8	7
India	18	5	4
China	40	15	13
OECD Pacific	13	6	6
International Bunkers	51	21	14
Global	295	130	110

6.1.5. Carbon dioxide emission in the transport sector by transport mode

The cumulative carbon emissions for all regions and under all scenarios clearly shows that the road transport sector takes up at least 80% of energy-related CO_2 emissions until 2050. Figure 35 and Figure 36 show the CO_2 emission breakdown for each transport mode and region. The second highest emitting sector – with a global average share of 5% (minimum 1% in Middle East and maximum in North America with 7%) under the 1.5°C pathway is aviation. On global average, both rail and navigation follow with 3% of the total cumulative CO_2 emissions, although with significant regional variations due to different starting points of rail electrification rates. While the overall emissions are about 2.5 times higher under the Reference case, the shares by transport mode are similar: Road transport is responsible for 85% to 95% of the regional emissions, followed by aviation with 6% on global average (minimum share in Middle East is 1% with the highest shares in OECD North America (10%) and OECD Pacific (9%).

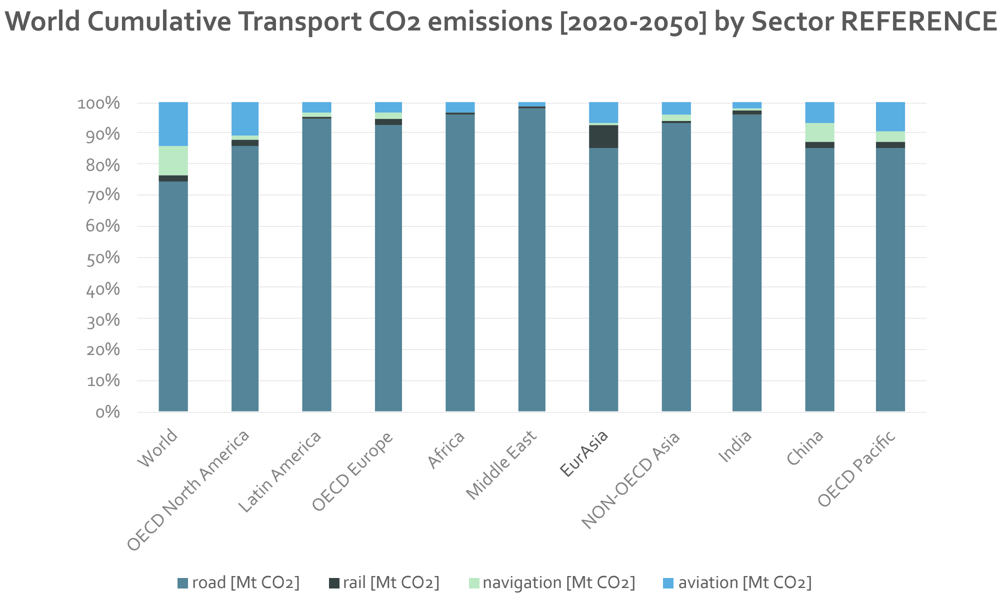

Figure 35. Reference: Cumulative CO_2 Transport Emissions by transport mode and region [2020-2050]

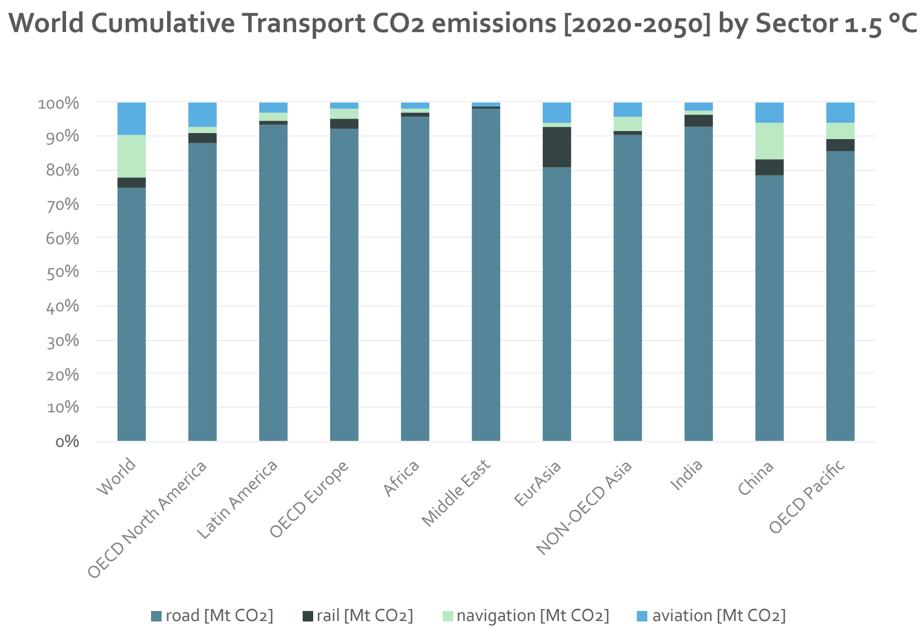

Figure 36. 1.5°C: Cumulative CO_2 Transport Emissions by transport mode and region [2020-2050]

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7. Policy Recommendations

A global decarbonization of the transport sector is possible as shown in the 1.5°C scenario. However, a drastic shift in policy is required. Condensed from global back-casting efforts on energy intensities, carbon emissions, trends, and drivers in 10 world regions, a potential pathway to a decarbonised transport sector could be based on the following steps (Figure 37):

1. **Avoid** or reduce the need to travel;
2. **Shift** to more efficient transport modes;
3. **Improve** efficiency through vehicle technology.

To decarbonize the remaining energy, demanding a fourth step is required:

4. **Phase-out fossil fuels** via increased electrification and the use of synthetic fuels produced by renewable energy.

To implement the 4 steps above – three different policy types are required:

1. Policies focused on transport infrastructure;
2. Policies focused on build environments;
3. Policies focused on technology change.

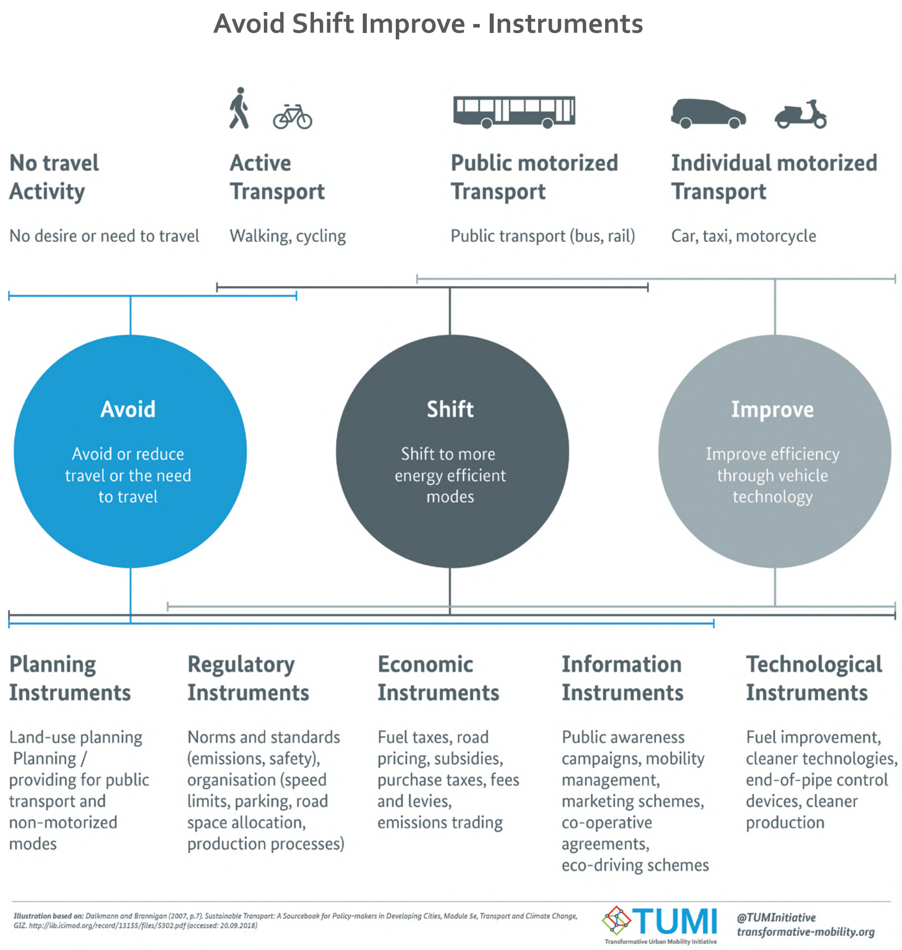

Figure 37. Avoid Shift Improve Instruments

Policies focused on transport infrastructure

The basic requirement for a shift from individual car-dominated transport towards one that favors public transport, cycling, and walking is the provision of the necessary infrastructure

A. Encourage walking and cycling via enhanced:

- Investments in comfortable bike lanes;
- Investments in secure and green walking pathways.
- Use sustainable mobility capitals (e.g. Amsterdam & Copenhagen) as reference.

B. Double public transport capacity by 2030:

- Acceptance for public transport increases with service quality and convenience.
- Light rail, rail, buses, and taxis must work hand-in-hand.

C. Support shared mobility for passenger transport from cars to scooters, from bikes to buses on demand.

D. Restructure urban freight logistics and implement cargo-bikes.

Policies focused on build environments

A. Support architectural solutions that make build environments more enjoyable for biking and walking.

B. Reduce transport demand reduction via urban planning to reduce average commute distances.

C. Implement 'Short Distance City': Working, living, shopping in walkable distances.

Policies focused on technology change

Specific CO2 emissions for aviation, navigation, and road transport need to drop between 2025 and 2045 significantly. The main technology changes come in the form of increased shares of electric drives, the use of synthetic and hydrogen fuels (produced with renewable electricity), and the limited use of sustainable biofuel which are produced based on residual organic waste. The use of biofuel from energy crops is not assumed under the OECM pathways.

In 2050, all transport fuels need to be carbon-free and only renewably produced fuels and renewably generated electricity are to be used.

This shift will occur by undertaking the following:

- Switch to electric mobility by electrifying road and rail
- Phase-out International Combustion Engines (ICE) for new vehicles by 2030;
- Implement mandatory efficiency standards for all vehicle types with an annual efficiency improvement target of 2% per year;
- Increase renewable electricity generation analogue to increased transport electricity demand;
- Limit sustainable biofuels and hydrogen to heavy duty trucks and machinery, navigation, and aviation;
- Limit the use of hydrogen and synthetic fuels to heavy duty machinery, aviation, and shipping;
- Hydrogen and synthetic fuels must be produced by renewable electricity.


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8. Endnotes

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"Stabilising atmospheric CO2 at 450 ppm, which will likely result in a global equilibrium warming of 1.4°C to 3.1°C, with a best guess of about 2.1°C. (...) For higher stabilisation scenarios such as SP550, SP750 and SP1000, the larger warming (2.9°C, 4.3°C and 5.5°C, respectively) requires an increasingly larger reduction (130 to 425 GtC, 160 to 500 GtC and 165 to 510 GtC, respectively) in the cumulated compatible emissions."

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9. Data Annex

9.1. OECD North America

9.1.1. Development of transport demand

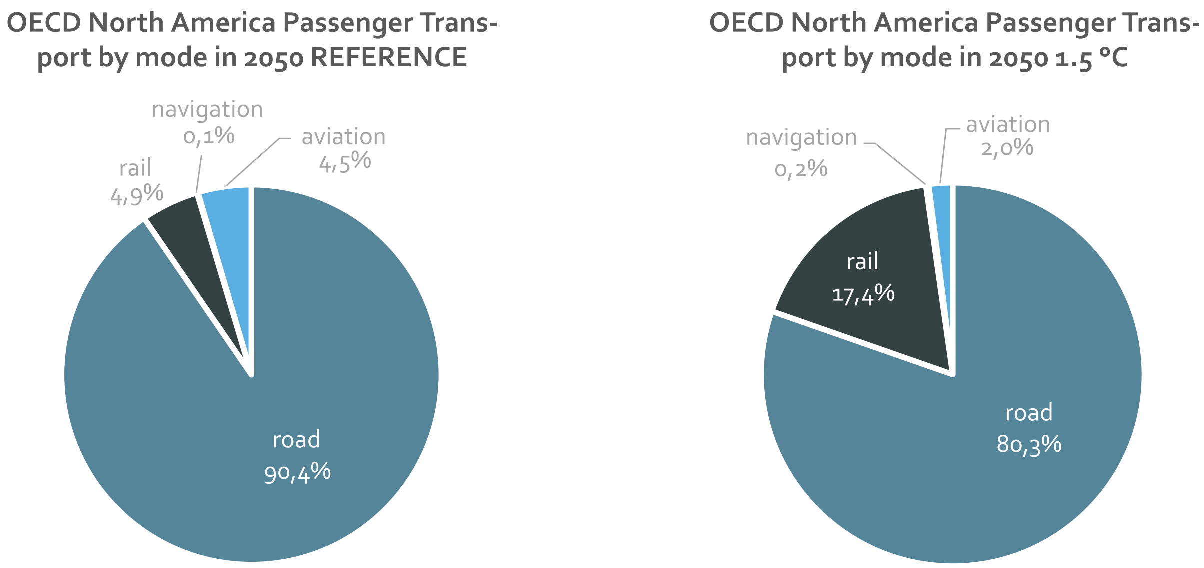


Figure 38. OECD North America: Development of passenger transport under two scenarios by mode by 2050

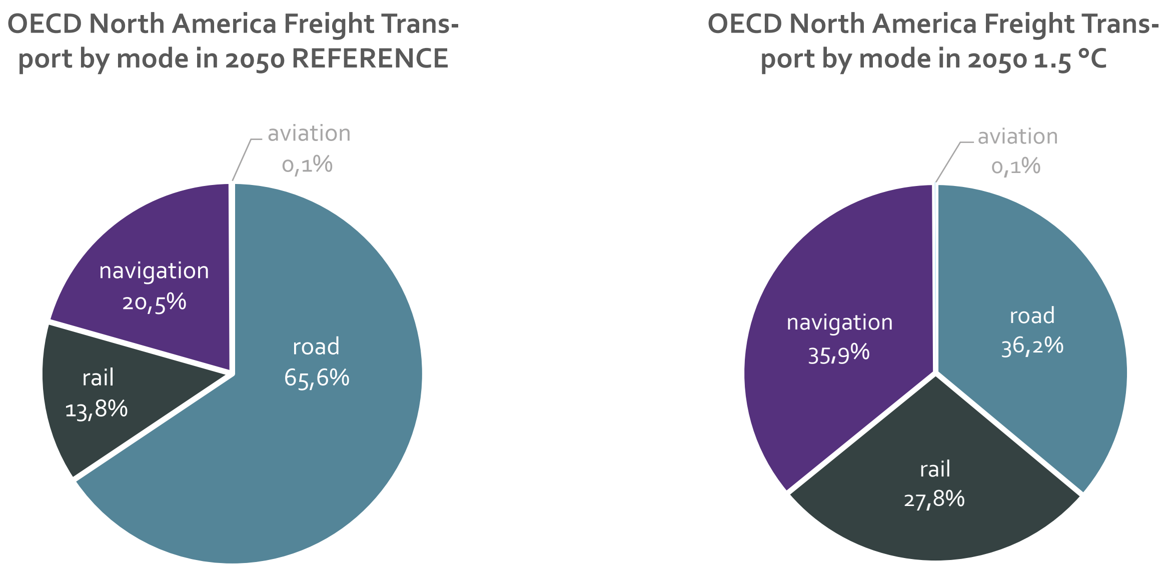


Figure 39. OECD North America: Development of freight transport under two scenarios by mode by 2050

Table 27. OECD North America: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	126%	146%	153%	161%
	2.0°C	100%	129%	165%	232%	269%	312%
	1.5°C	100%	134%	188%	253%	286%	323%
Road	REF	100%	106%	108%	110%	112%	113%
	2.0°C	100%	107%	101%	77%	69%	63%
	1.5°C	100%	103%	88%	70%	63%	57%
Domestic aviation	REF	100%	133%	174%	199%	209%	219%
	2.0°C	100%	102%	99%	90%	85%	77%
	1.5°C	100%	101%	96%	75%	64%	55%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	103%	108%	120%	126%	132%
	1.5°C	100%	103%	120%	153%	173%	196%
Total	REF	100%	107%	110%	114%	116%	118%
	2.0°C	100%	107%	104%	83%	77%	72%
	1.5°C	100%	104%	92%	77%	71%	67%

Table 28. OECD North America: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	126%	139%	146%	154%
	2.0°C	100%	125%	156%	220%	255%	296%
	1.5°C	100%	130%	183%	234%	264%	299%
Road	REF	100%	136%	140%	147%	151%	154%
	2.0°C	100%	118%	112%	89%	81%	73%
	1.5°C	100%	130%	123%	112%	96%	82%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	76%	65%	56%
Domestic navigation	REF	100%	106%	112%	117%	120%	123%
	2.0°C	100%	106%	119%	153%	173%	196%
	1.5°C	100%	105%	121%	163%	189%	209%
Total	REF	100%	126%	131%	139%	143%	147%
	2.0°C	100%	116%	120%	122%	126%	132%
	1.5°C	100%	124%	131%	140%	141%	142%

9.1.2. Development of transport services

Table 29. OECD North America: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	768	768	761	786	750	800
	2.0°C	768	768	776	869	980	1,087
	1.5°C	768	768	739	863	956	1,111
Road	REF	27,724	25,141	24,452	23,239	22,696	22,758
	2.0°C	27,724	25,141	22,879	18,822	10,050	6,084
	1.5°C	27,724	25,141	22,836	17,329	9,766	6,083
Domestic aviation	REF	2,844	2,104	2,296	2,773	3,010	3,237
	2.0°C	2,844	2,104	1,798	1,633	1,405	1,175
	1.5°C	2,844	2,104	1,792	1,591	1,172	845
Domestic navigation	REF	464	425	436	450	459	472
	2.0°C	464	425	434	480	589	728
	1.5°C	464	425	430	490	635	792
Total	REF	32,565	29,204	27,945	27,248	26,915	27,267
	2.0°C	32,565	29,204	25,887	21,804	13,024	9,074
	1.5°C	32,565	29,204	25,796	20,274	12,529	8,831

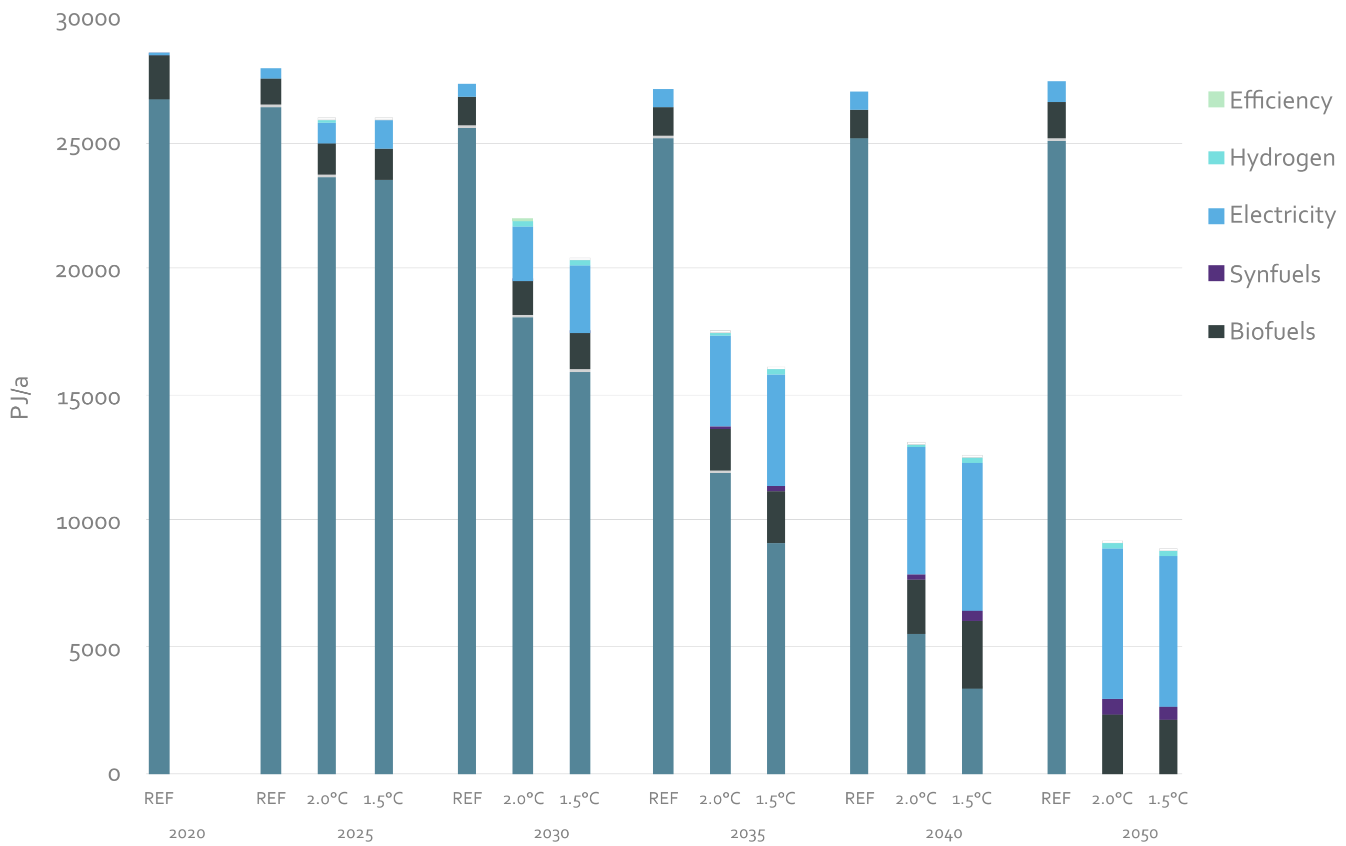
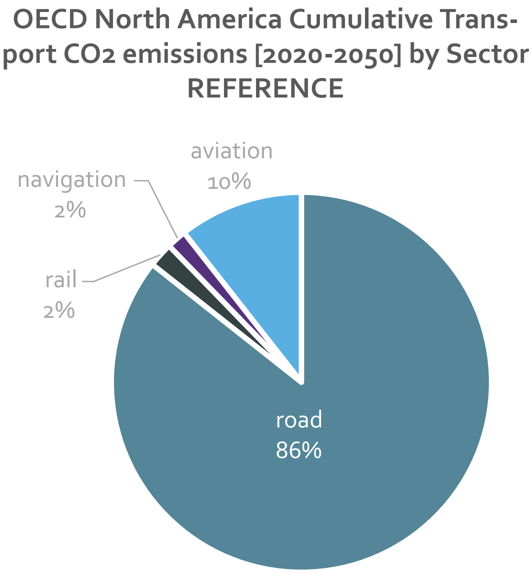


Figure 40. OECD North America: Final energy consumption transport under three scenarios

Table 30. OECD North America: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	60	60	55	47	29	28
	2.0°C	60	60	56	47	18	0
	1.5°C	60	60	53	40	8	0
Road	REF	2,268	2,065	1,848	1,706	1,609	1,573
	2.0°C	2,268	2,065	1,727	1,312	365	0
	1.5°C	2,268	2,065	1,724	1,187	285	0
Domestic aviation	REF	213	158	172	208	226	243
	2.0°C	213	158	135	119	64	0
	1.5°C	213	158	135	116	19	0
Domestic navigation	REF	36	33	33	34	34	35
	2.0°C	36	33	33	35	27	0
	1.5°C	36	33	32	33	12	0
Total	REF	2,578	2,316	2,107	1,994	1,898	1,880
	2.0°C	2,578	2,316	1,951	1,513	474	0
	1.5°C	2,578	2,316	1,944	1,376	324	0



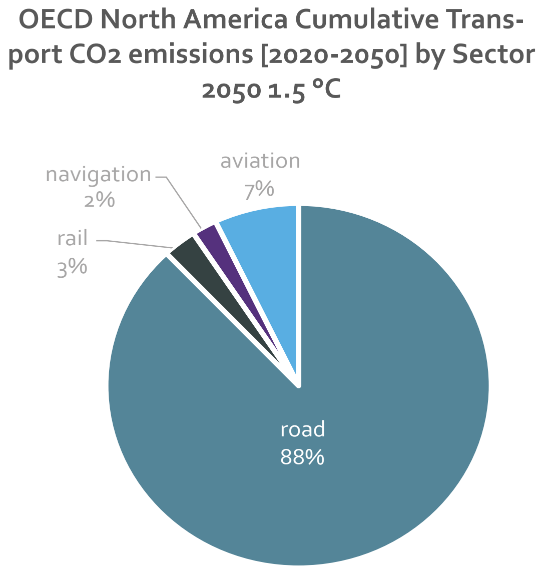


Figure 41. OECD North America: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 63 Gt CO_2

2.0°C: 34 Gt CO_2

1.5°C: 31 Gt CO_2

9.2. Latin America

9.2.1. Development of transport demand

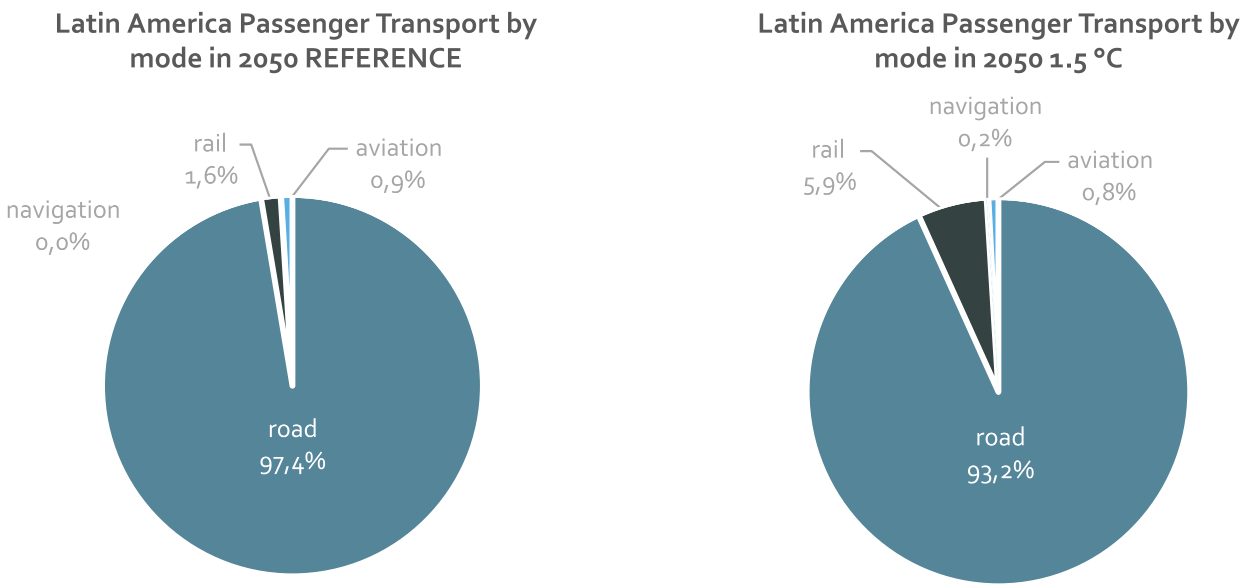


Figure 42. Latin America: Development of passenger transport under two scenarios by mode by 2050

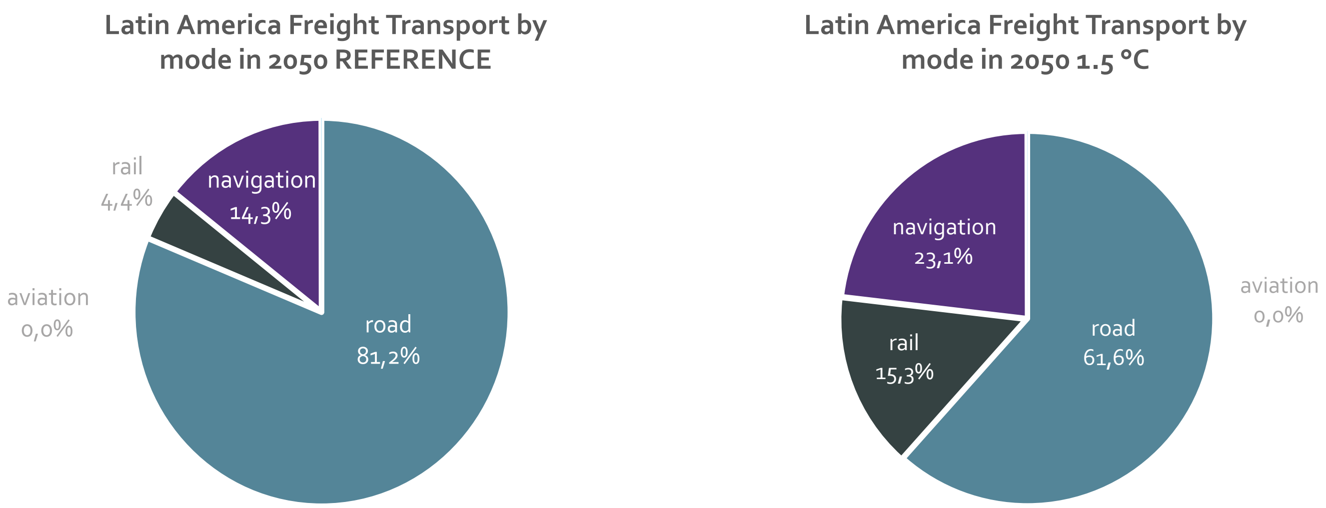


Figure 43. Latin America: Development of freight transport under two scenarios by mode by 2050

Table 31. Latin America: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	117%	129%	157%	173%	192%
	2.0°C	100%	120%	146%	197%	228%	264%
	1.5°C	100%	120%	146%	216%	263%	320%
Road	REF	100%	163%	208%	254%	280%	309%
	2.0°C	100%	129%	136%	143%	145%	146%
	1.5°C	100%	127%	130%	137%	139%	139%
Domestic aviation	REF	100%	121%	140%	179%	188%	198%
	2.0°C	100%	105%	100%	88%	84%	80%
	1.5°C	100%	105%	100%	90%	86%	82%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	103%	113%	138%	152%	168%
	1.5°C	100%	103%	116%	149%	168%	190%
Total	REF	100%	161%	205%	250%	276%	304%
	2.0°C	100%	129%	136%	144%	146%	148%
	1.5°C	100%	126%	130%	138%	141%	143%

Table 32. Latin America: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	116%	122%	134%	141%	148%
	2.0°C	100%	119%	145%	214%	274%	366%
	1.5°C	100%	121%	148%	229%	293%	374%
Road	REF	100%	251%	278%	338%	374%	412%
	2.0°C	100%	212%	223%	235%	237%	239%
	1.5°C	100%	206%	211%	222%	225%	226%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	76%	65%	56%
Domestic navigation	REF	100%	109%	114%	126%	129%	133%
	2.0°C	100%	110%	119%	131%	138%	145%
	1.5°C	100%	112%	124%	140%	147%	155%
Total	REF	100%	193%	211%	252%	274%	299%
	2.0°C	100%	171%	183%	199%	209%	220%
	1.5°C	100%	168%	177%	196%	206%	216%

9.2.2. Development of transport services

Table 33. Latin America: Projection of transport energy demand by sector in [PJ/a]

		2020	2025	2030	2040	2045	2050
Rail	REF	63	63	85	83	93	103
	2.0°C	63	63	89	97	111	144
	1.5°C	63	63	83	84	109	155
Road	REF	6,662	6,662	6,873	7,768	8,947	10,582
	2.0°C	6,662	6,662	5,478	5,006	3,837	3,076
	1.5°C	6,662	6,662	5,280	4,627	3,331	2,903
Domestic aviation	REF	211	211	211	228	274	296
	2.0°C	211	211	186	165	139	121
	1.5°C	211	211	186	165	139	121
Domestic navigation	REF	101	101	107	110	118	121
	2.0°C	101	101	108	115	124	135
	1.5°C	101	101	110	120	132	144
Total	REF	7,114	7,114	7,275	8,190	9,432	11,102
	2.0°C	7,114	7,114	5,862	5,383	4,210	3,476
	1.5°C	7,114	7,114	5,658	4,995	3,711	3,324

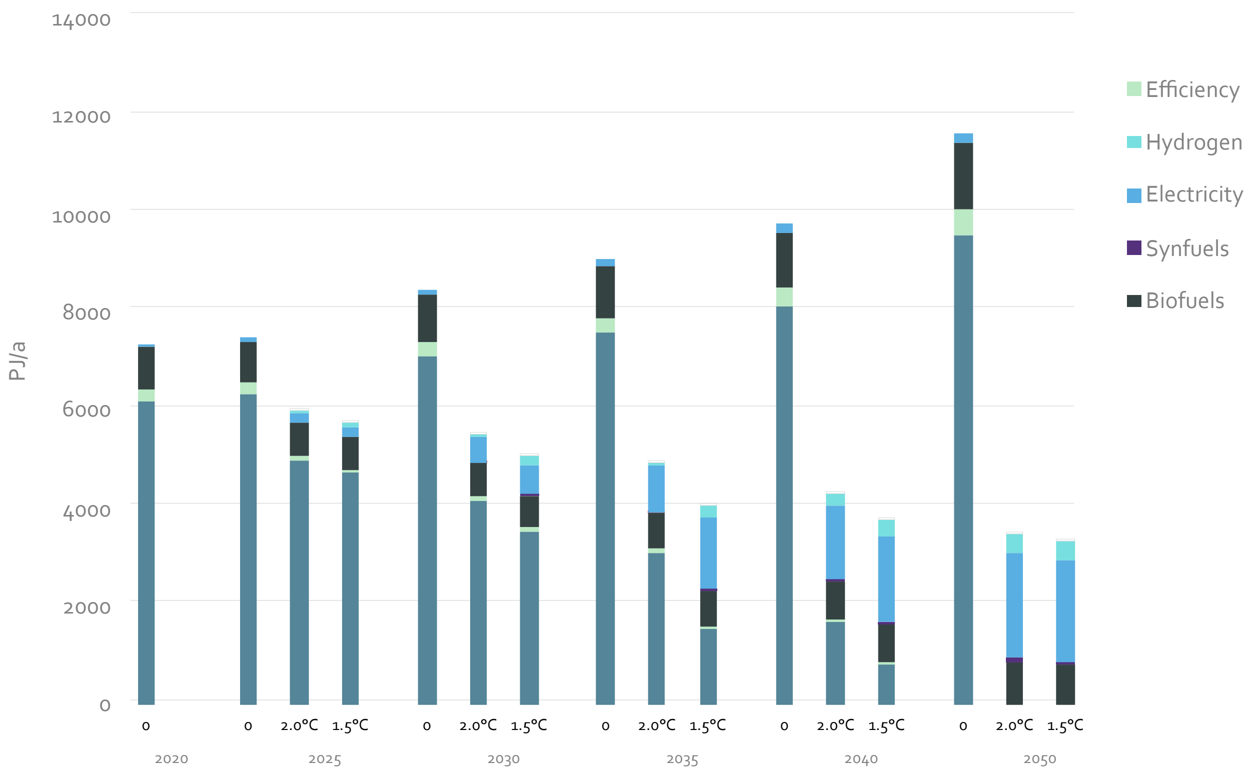
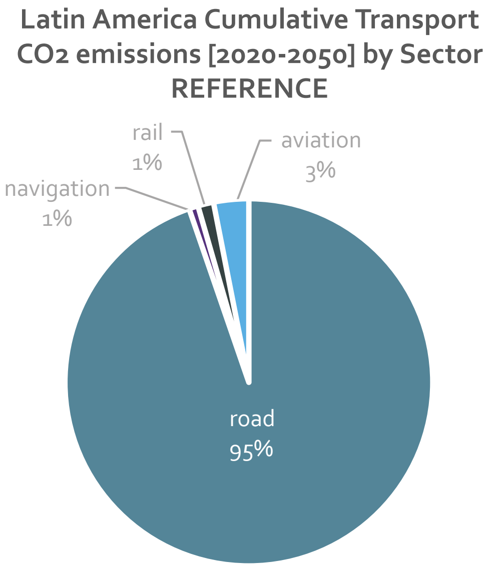


Figure 44. Latin America: Final energy consumption transport under three scenarios

Table 34. Latin America: CO_2 emission by transport sector in [million-ton CO_2/a]

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	116%	122%	134%	141%	148%
	2.0°C	100%	119%	145%	214%	274%	366%
	1.5°C	100%	121%	148%	229%	293%	374%
Road	REF	100%	251%	278%	338%	374%	412%
	2.0°C	100%	212%	223%	235%	237%	239%
	1.5°C	100%	206%	211%	222%	225%	226%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	76%	65%	56%
Domestic navigation	REF	100%	109%	114%	126%	129%	133%
	2.0°C	100%	110%	119%	131%	138%	145%
	1.5°C	100%	112%	124%	140%	147%	155%
Total	REF	100%	193%	211%	252%	274%	299%
	2.0°C	100%	171%	183%	199%	209%	220%
	1.5°C	100%	168%	177%	196%	206%	216%



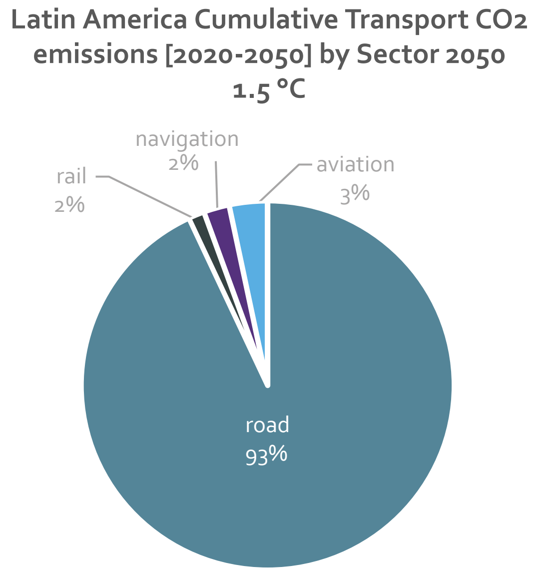


Figure 45. Latin America: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 19 Gt CO_2

2.0°C: 8 Gt CO_2

1.5°C: 7 Gt CO_2

9.3. OECD Europe

9.3.1. Development of transport demand

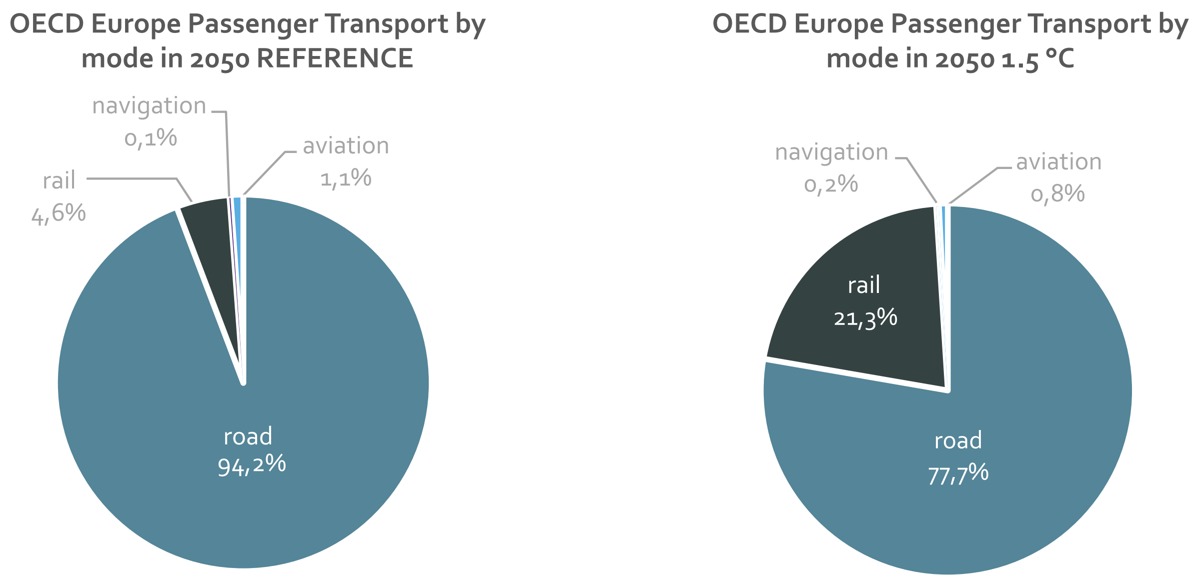


Figure 46. OECD Europe: Development of passenger transport under two scenarios by mode by 2050

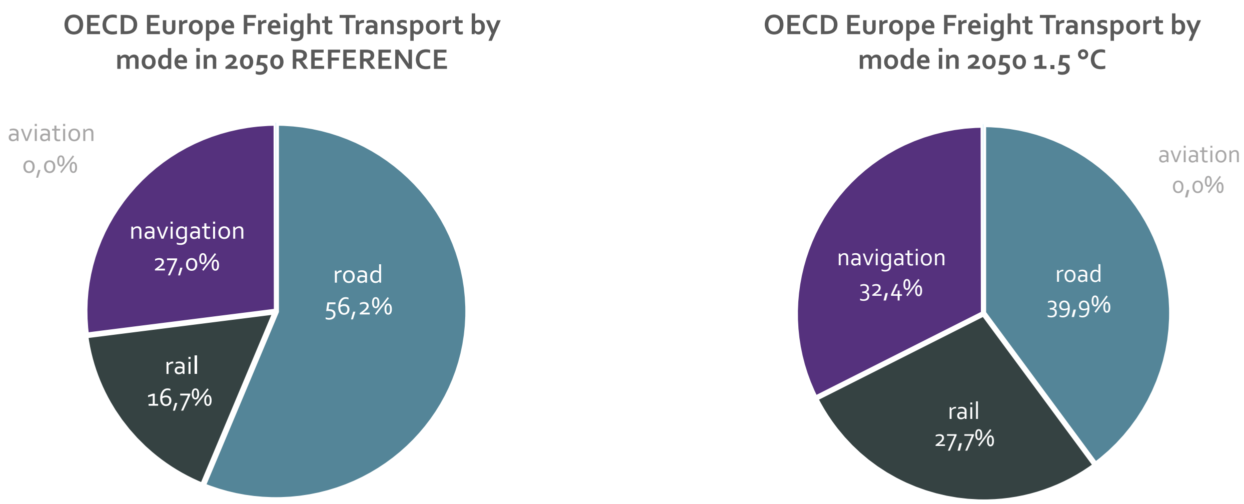


Figure 47. OECD Europe: Development of freight transport under two scenarios by mode by 2050

Table 35. OECD Europe: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	130%	137%	145%	147%	149%
	2.0°C	100%	105%	110%	155%	180%	209%
	1.5°C	100%	116%	148%	230%	279%	340%
Road	REF	100%	108%	113%	125%	131%	138%
	2.0°C	100%	105%	103%	101%	92%	83%
	1.5°C	100%	106%	100%	76%	65%	56%
Domestic aviation	REF	100%	133%	154%	187%	207%	228%
	2.0°C	100%	103%	105%	95%	91%	86%
	1.5°C	100%	101%	96%	87%	83%	79%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	102%	107%	118%	124%	131%
	1.5°C	100%	103%	113%	138%	152%	168%
Total	REF	100%	109%	114%	126%	133%	139%
	2.0°C	100%	105%	103%	104%	95%	88%
	1.5°C	100%	106%	102%	83%	75%	68%

Table 36. OECD Europe: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	130%	137%	151%	167%	184%
	2.0°C	100%	125%	156%	231%	281%	342%
	1.5°C	100%	125%	156%	231%	281%	342%
Road	REF	100%	118%	124%	129%	131%	132%
	2.0°C	100%	118%	112%	85%	73%	63%
	1.5°C	100%	118%	112%	85%	73%	63%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	91%	82%	74%
Domestic navigation	REF	100%	106%	112%	117%	120%	123%
	2.0°C	100%	106%	112%	117%	120%	123%
	1.5°C	100%	106%	112%	117%	120%	123%
Total	REF	100%	116%	122%	128%	132%	136%
	2.0°C	100%	115%	117%	111%	111%	112%
	1.5°C	100%	115%	117%	111%	111%	112%

9.3.2. Development of transport services

Table 37. OECD Europe: Projection of transport energy demand by sector in [PJ/a]

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	130%	137%	151%	167%	184%
	2.0°C	100%	106%	132%	195%	238%	289%
	1.5°C	100%	107%	134%	198%	240%	293%
Road	REF	100%	108%	113%	118%	119%	120%
	2.0°C	100%	105%	100%	76%	65%	56%
	1.5°C	100%	106%	103%	91%	86%	82%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	99%	94%	92%	90%
	1.5°C	100%	102%	98%	91%	82%	74%
Domestic navigation	REF	100%	106%	112%	117%	120%	123%
	2.0°C	100%	107%	115%	124%	128%	131%
	1.5°C	100%	108%	120%	135%	139%	142%
Total	REF	100%	110%	116%	121%	125%	129%
	2.0°C	100%	107%	111%	116%	119%	124%
	1.5°C	100%	106%	108%	104%	103%	102%

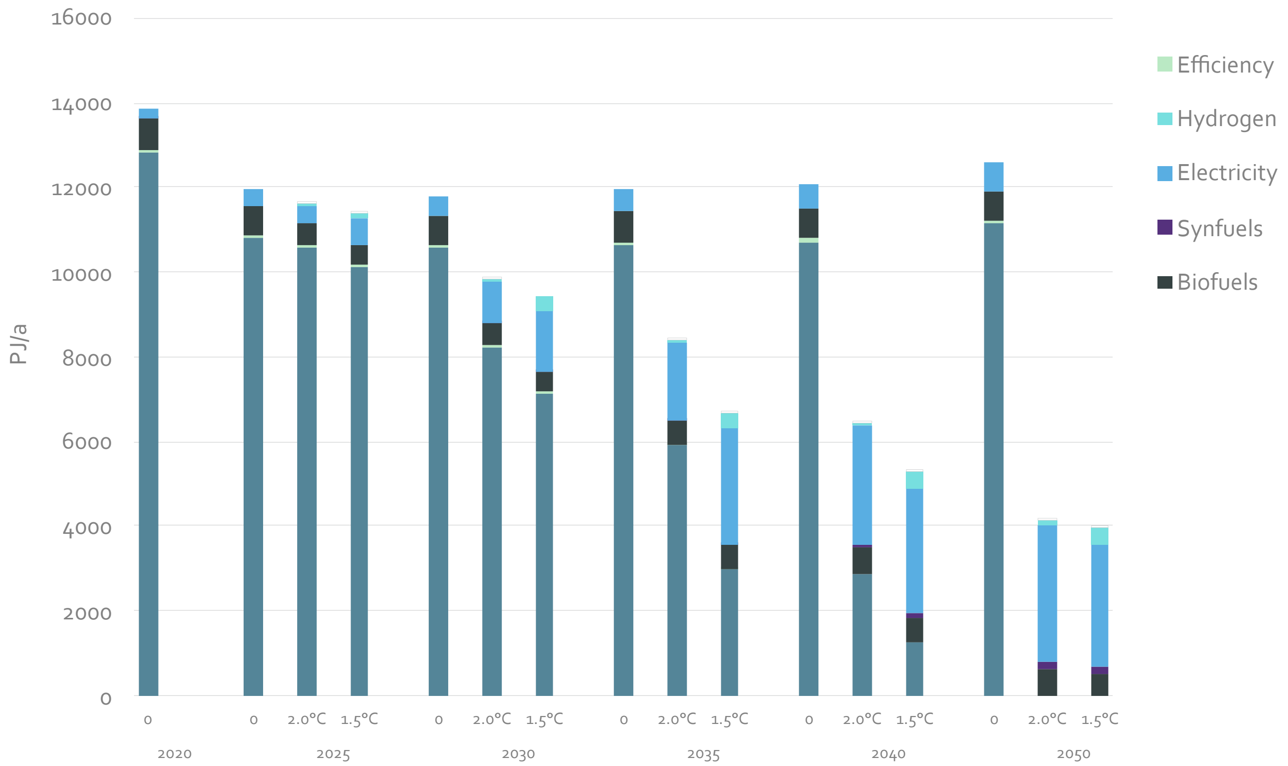


Figure 48. OECD Europe: Final energy consumption transport under three scenarios

Table 38. OECD Europe: CO_2 emission by transport sector in [million-ton CO_2 /a]

		2019	2020	2025	2030	2040	2050
Rail	REF	336	312	322	323	330	355
	2.0°C	336	312	323	334	389	458
	1.5°C	336	312	313	327	417	564
Road	REF	13,986	12,942	11,041	10,832	11,037	11,445
	2.0°C	13,986	12,942	10,752	8,990	5,595	3,186
	1.5°C	13,986	12,942	10,514	8,501	4,386	2,929
Domestic aviation	REF	376	278	302	326	375	444
	2.0°C	376	278	240	228	196	175
	1.5°C	376	278	237	210	181	158
Domestic navigation	REF	267	248	256	265	270	278
	2.0°C	267	248	259	274	286	294
	1.5°C	267	248	261	284	312	324
Total	REF	15,065	13,878	11,921	11,746	12,013	12,523
	2.0°C	15,065	13,878	11,574	9,826	6,466	4,114
	1.5°C	15,065	13,878	11,325	9,322	5,297	3,975

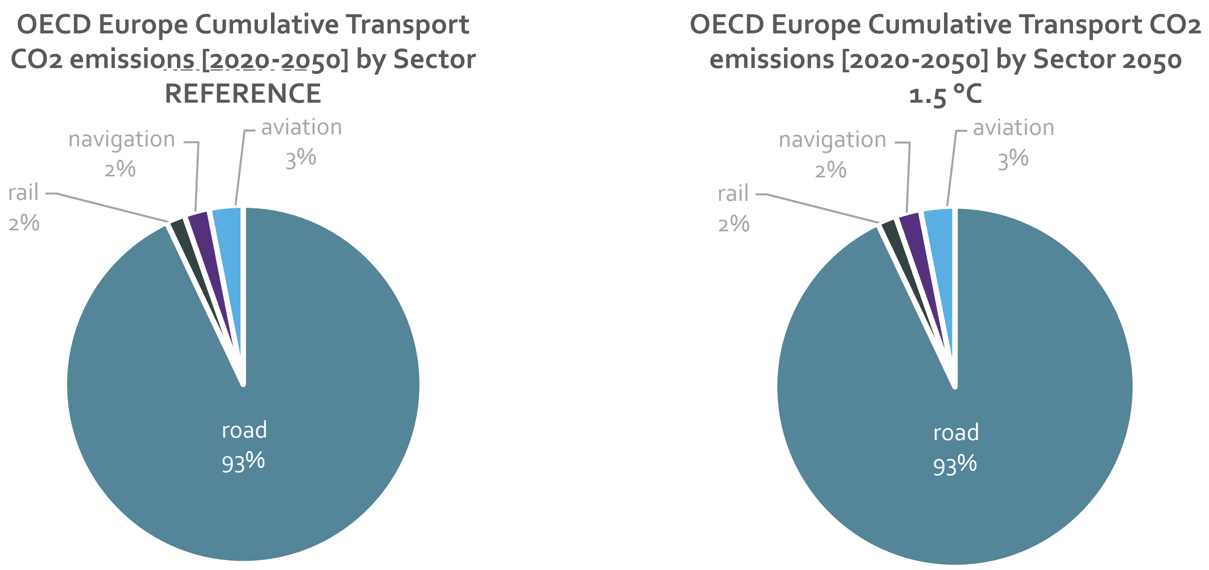


Figure 49. OECD Europe: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 27 Gt CO_2

2.0°C: 15 Gt CO_2

1.5°C: 13 Gt CO_2

9.4. Middle East

9.4.1. Development of transport demand

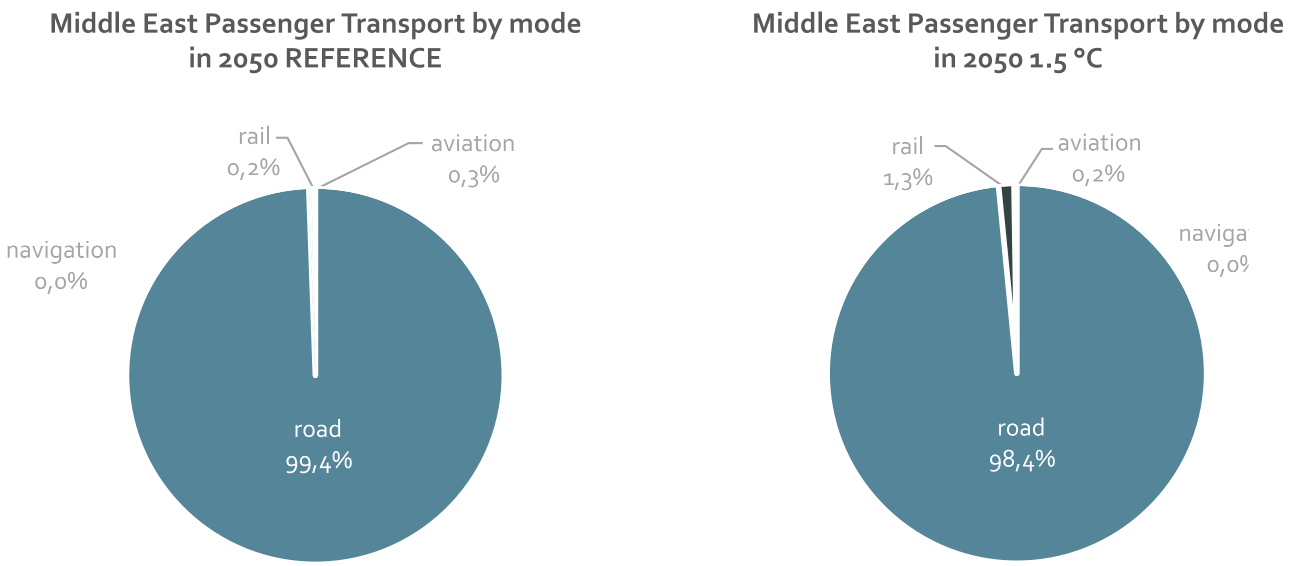


Figure 50. Middle East: Development of passenger transport under two scenarios by mode by 2050

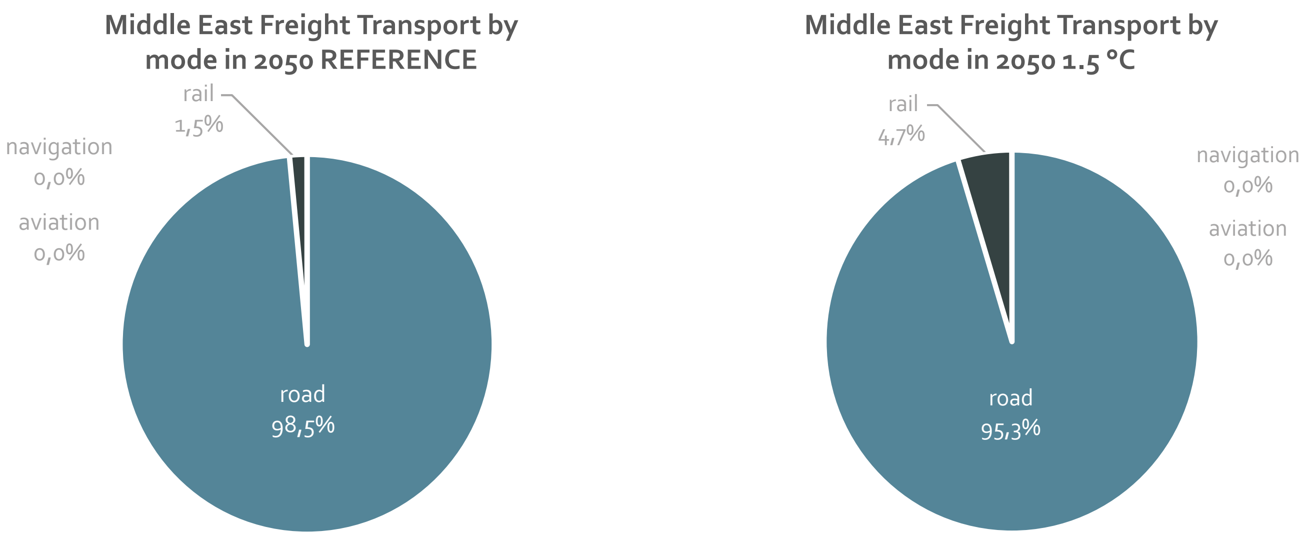


Figure 51. Middle East: Development of freight transport under two scenarios by mode by 2050

Table 39. Middle East: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	126%	146%	153%	161%
	2.0°C	100%	105%	122%	180%	219%	267%
	1.5°C	100%	120%	153%	250%	319%	407%
Road	REF	100%	147%	179%	264%	322%	391%
	2.0°C	100%	141%	156%	172%	181%	190%
	1.5°C	100%	140%	147%	162%	166%	171%
Domestic aviation	REF	100%	161%	211%	241%	253%	265%
	2.0°C	100%	114%	117%	117%	115%	112%
	1.5°C	100%	110%	105%	95%	90%	86%
Domestic navigation	REF	100%	100%	100%	100%	100%	100%
	2.0°C	100%	100%	100%	100%	100%	100%
	1.5°C	100%	100%	100%	100%	100%	100%
Total	REF	100%	147%	179%	264%	320%	390%
	2.0°C	100%	141%	155%	172%	181%	190%
	1.5°C	100%	140%	147%	162%	167%	171%

Table 40. Middle East: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	117%	136%	166%	183%	202%
	2.0°C	100%	125%	156%	220%	255%	296%
	1.5°C	100%	125%	156%	220%	255%	296%
Road	REF	100%	148%	180%	267%	324%	395%
	2.0°C	100%	147%	170%	197%	207%	218%
	1.5°C	100%	142%	150%	174%	178%	182%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	91%	82%	74%
Domestic navigation	REF	100%	100%	100%	100%	100%	100%
	2.0°C	100%	100%	100%	100%	100%	100%
	1.5°C	100%	100%	100%	100%	100%	100%
Total	REF	100%	147%	179%	264%	320%	390%
	2.0°C	100%	141%	155%	172%	181%	190%
	1.5°C	100%	140%	147%	162%	167%	171%

9.4.2. Development of transport services

Table 41. Middle East: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	100%	117%	136%	166%	183%	202%
	2.0°C	100%	110%	141%	229%	293%	374%
	1.5°C	100%	125%	156%	220%	255%	296%
Road	REF	100%	147%	179%	264%	322%	391%
	2.0°C	100%	145%	169%	196%	206%	216%
	1.5°C	100%	140%	147%	170%	175%	179%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	98%	91%	82%	74%
Domestic navigation	REF	100%	100%	100%	100%	100%	100%
	2.0°C	100%	100%	100%	100%	100%	100%
	1.5°C	100%	100%	100%	100%	100%	100%
Total	REF	100%	146%	177%	262%	318%	386%
	2.0°C	100%	144%	168%	197%	208%	221%
	1.5°C	100%	139%	147%	172%	177%	183%

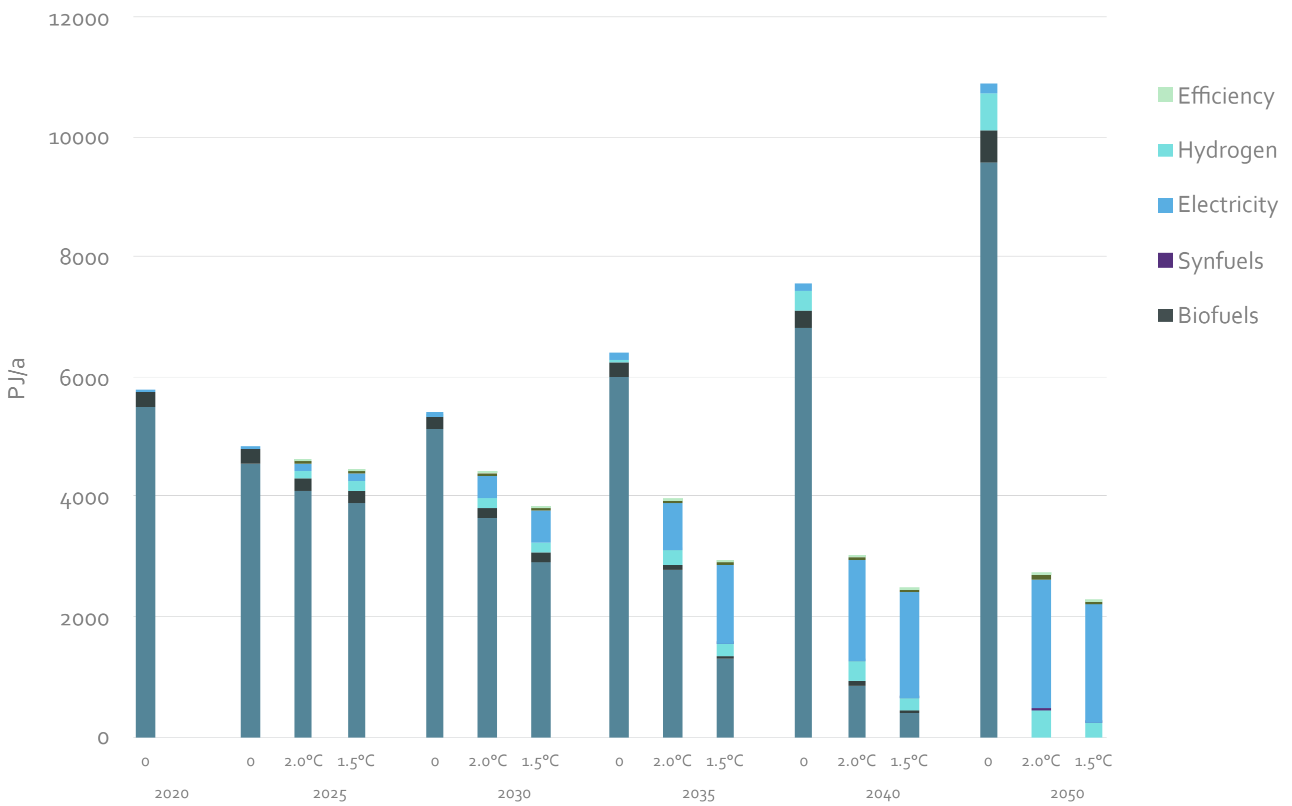
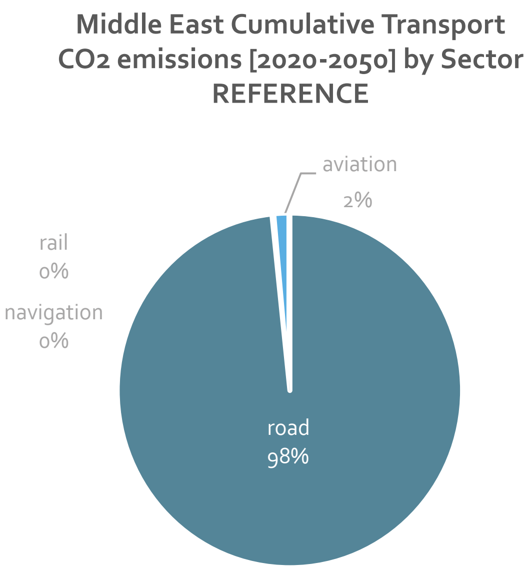


Figure 52. Middle East: Final energy consumption transport under three scenarios

Table 42. Middle East: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	23	23	22	23	17	19
	2.0°C	23	23	23	26	19	25
	1.5°C	23	23	26	15	19	25
Road	REF	5,425	5,425	4,498	5,101	7,128	10,225
	2.0°C	5,425	5,425	4,272	4,137	2,890	2,613
	1.5°C	5,425	5,425	4,139	3,585	2,381	2,185
Domestic aviation	REF	57	57	74	89	97	104
	2.0°C	57	57	53	51	48	44
	1.5°C	57	57	52	46	40	35
Domestic navigation	REF	0	0	0	0	0	0
	2.0°C	0	0	0	0	0	0
	1.5°C	0	0	0	0	0	0
Total	REF	5,523	5,523	4,594	5,213	7,242	10,348
	2.0°C	5,523	5,523	4,348	4,214	2,957	2,682
	1.5°C	5,523	5,523	4,217	3,646	2,439	2,245



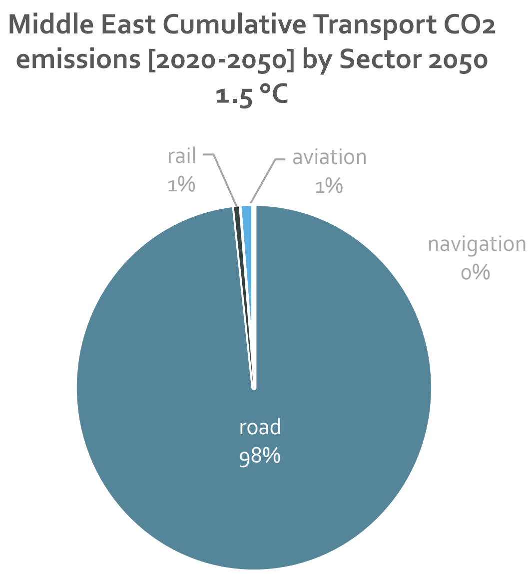


Figure 53. Middle East: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 15 Gt CO_2

2.0°C: 6 Gt CO_2

1.5°C: 5 Gt CO_2

9.5. Africa

9.5.1. Development of transport demand

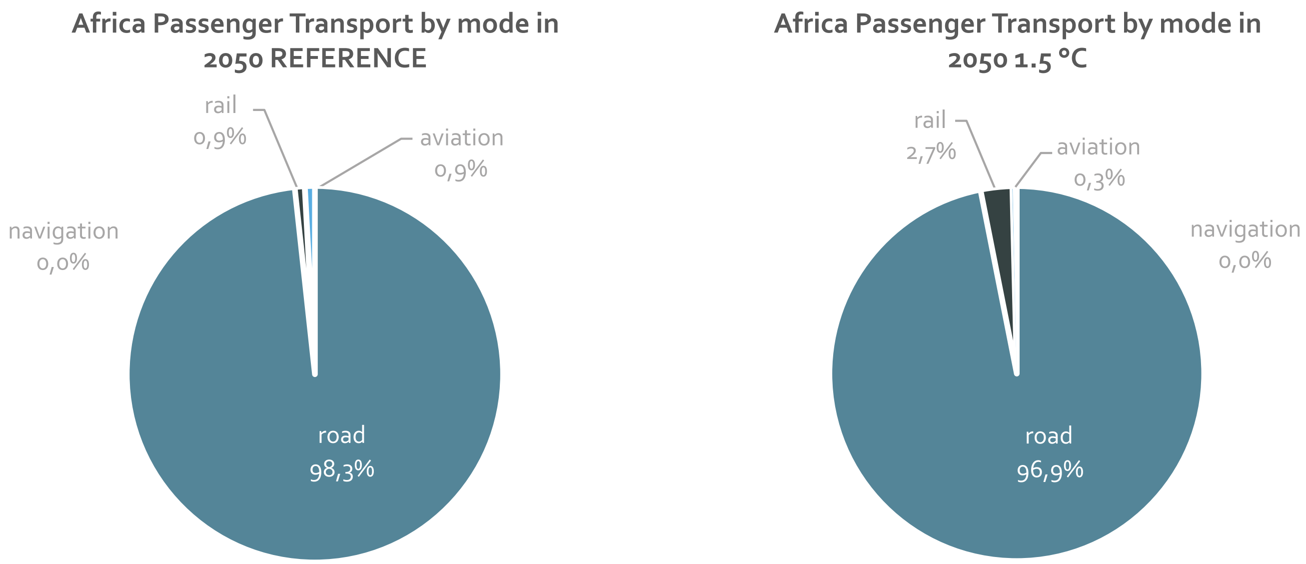


Figure 54. Africa: Development of passenger transport under two scenarios by mode by 2050

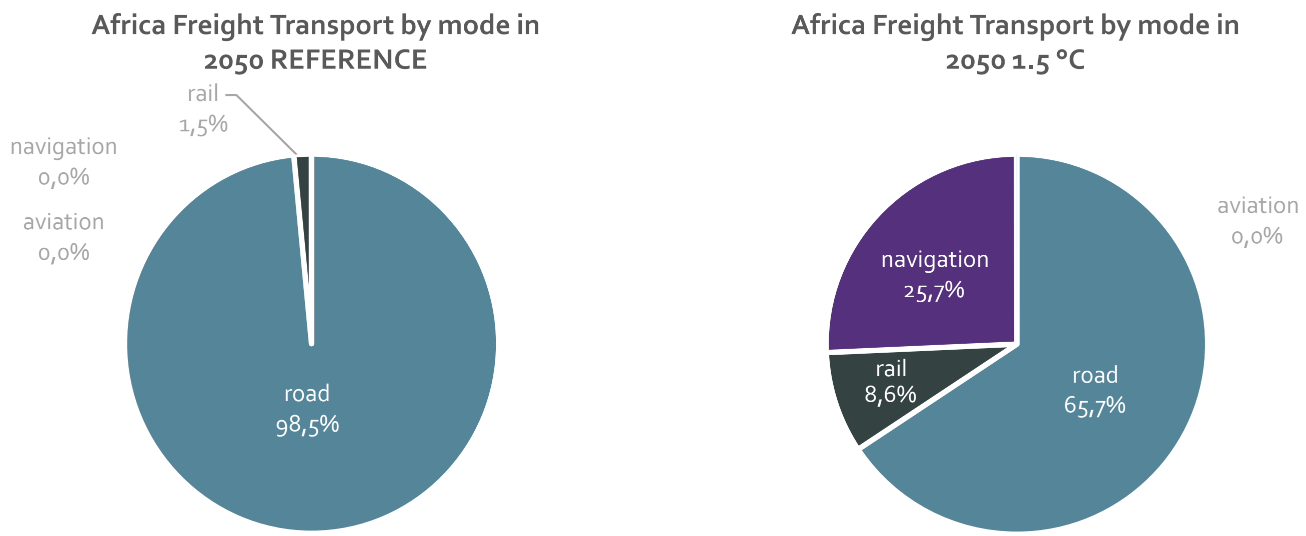


Figure 55. Africa: Development of freight transport under two scenarios by mode by 2050

Table 43. Africa: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	120%	133%	170%	197%	228%
	2.0°C	100%	110%	116%	189%	230%	280%
	1.5°C	100%	110%	141%	229%	293%	374%
Road	REF	100%	135%	164%	243%	295%	359%
	2.0°C	100%	116%	134%	163%	180%	199%
	1.5°C	100%	116%	122%	148%	164%	181%
Domestic aviation	REF	100%	161%	211%	283%	328%	381%
	2.0°C	100%	104%	109%	104%	102%	99%
	1.5°C	100%	101%	96%	87%	83%	79%
Domestic navigation	REF	100%	104%	110%	121%	134%	148%
	2.0°C	100%	104%	108%	138%	145%	152%
	1.5°C	100%	102%	107%	116%	122%	128%
Total	REF	100%	135%	164%	242%	294%	358%
	2.0°C	100%	115%	134%	163%	180%	199%
	1.5°C	100%	115%	122%	149%	165%	182%

Table 44. Africa: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	118%	137%	184%	213%	247%
	2.0°C	100%	107%	113%	184%	223%	272%
	1.5°C	100%	107%	130%	193%	235%	286%
Road	REF	100%	138%	153%	186%	205%	227%
	2.0°C	100%	121%	134%	163%	180%	199%
	1.5°C	100%	116%	122%	148%	164%	181%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	101%	99%	94%	92%	89%
	1.5°C	100%	102%	98%	91%	82%	74%
Domestic navigation	REF	100%	106%	112%	123%	136%	150%
	2.0°C	100%	110%	128%	172%	199%	231%
	1.5°C	100%	110%	141%	229%	293%	374%
Total	REF	100%	132%	146%	177%	196%	217%
	2.0°C	100%	119%	132%	166%	187%	216%
	1.5°C	100%	114%	125%	163%	186%	209%

9.5.2. Development of transport services

Table 45. Africa: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	46	46	47	50	57	73
	2.0°C	46	46	43	38	49	59
	1.5°C	46	46	40	42	49	69
Road	REF	4,182	4,182	4,576	5,048	6,699	9,168
	2.0°C	4,182	4,182	3,871	3,821	3,162	3,318
	1.5°C	4,182	4,182	3,762	3,155	2,610	2,438
Domestic aviation	REF	105	105	137	165	209	272
	2.0°C	105	105	92	89	80	75
	1.5°C	105	105	90	80	68	60
Domestic navigation	REF	32	32	33	35	37	44
	2.0°C	32	32	35	39	51	66
	1.5°C	32	32	35	43	66	104
Total	REF	4,396	4,396	4,793	5,299	7,001	9,558
	2.0°C	4,396	4,396	4,040	3,987	3,343	3,518
	1.5°C	4,396	4,396	3,926	3,320	2,794	2,671

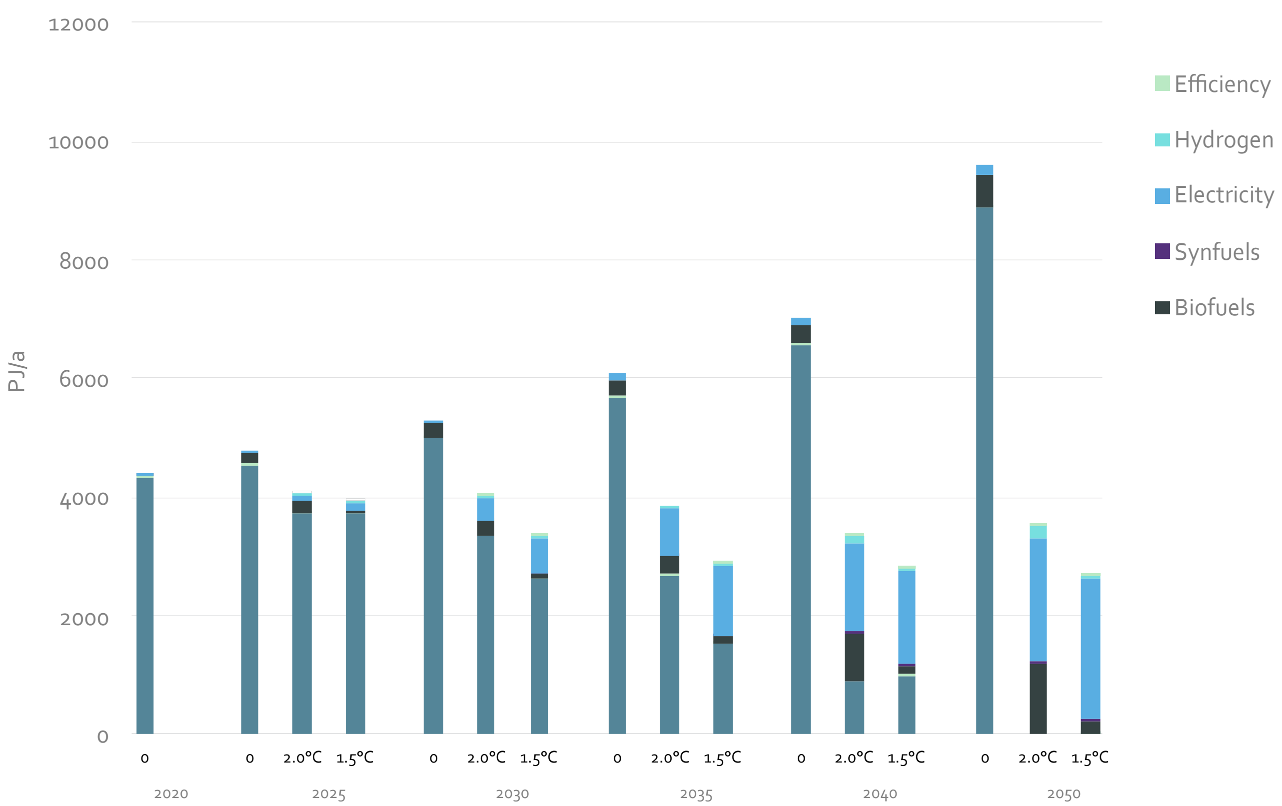
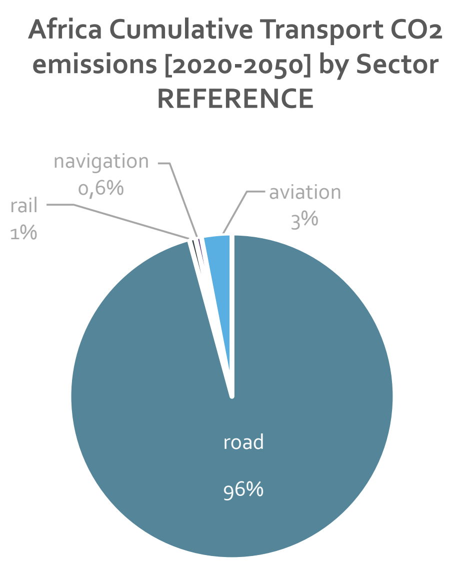


Figure 56. Africa: Final energy consumption transport under three scenarios

Table 46. Africa: CO2 emission by transport sector in [million-ton CO2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	5	5	3	3	2	3
	2.0°C	5	5	3	2	1	0
	1.5°C	5	5	3	2	0	0
Road	REF	314	314	346	371	475	638
	2.0°C	314	314	292	266	82	0
	1.5°C	314	314	281	213	86	1
Domestic aviation	REF	8	8	10	12	16	20
	2.0°C	8	8	7	7	4	0
	1.5°C	8	8	7	6	1	0
Domestic navigation	REF	2	2	3	3	3	3
	2.0°C	2	2	3	3	2	0
	1.5°C	2	2	3	3	1	0
Total	REF	329	329	362	389	496	664
	2.0°C	329	329	305	278	89	0
	1.5°C	329	329	293	224	89	1



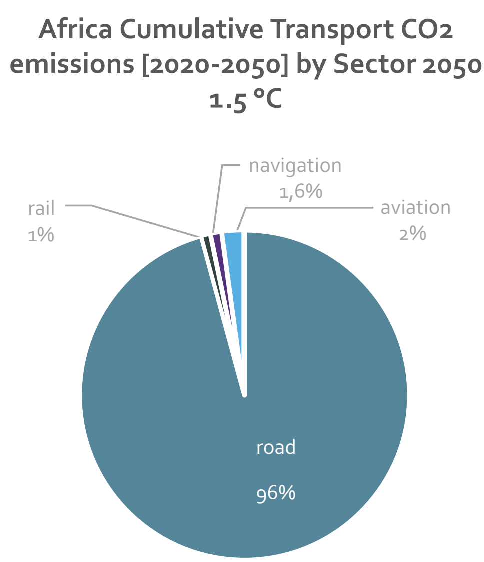


Figure 57. Africa: Cumulative CO2 Transport Emissions [2020-2050]

REFERENCE: 15 Gt CO2

2.0°C: 6 Gt CO2

1.5°C: 5 Gt CO2

9.6. Eurasia

9.6.1. Development of transport demand

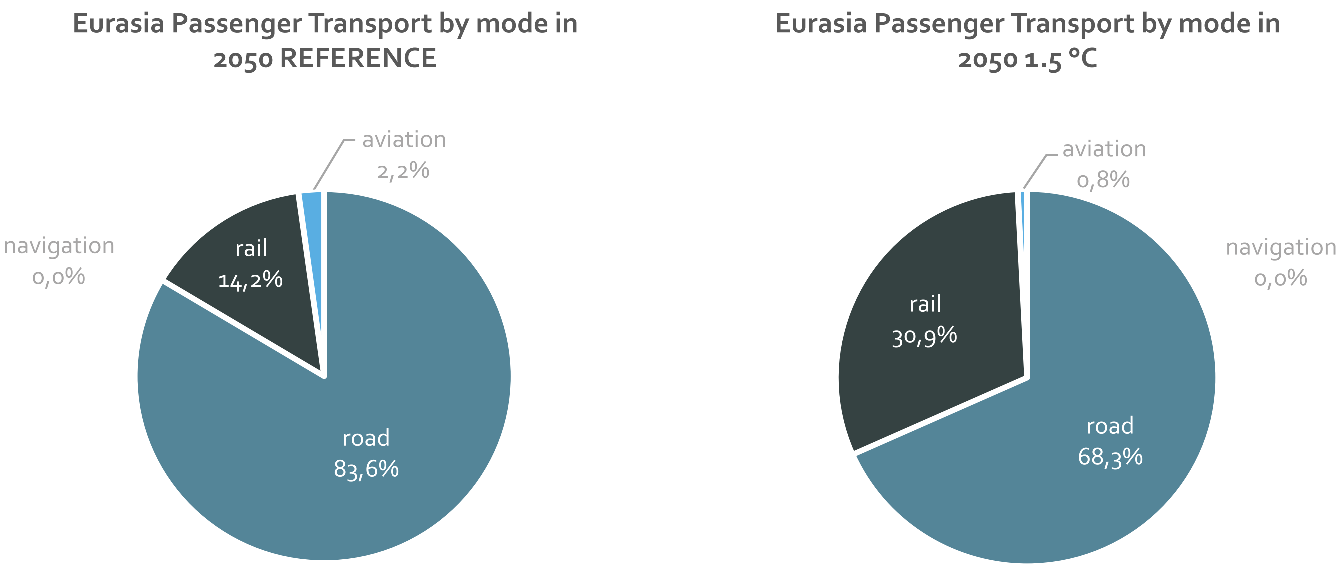


Figure 58. Eurasia: Development of passenger transport under two scenarios by mode by 2050

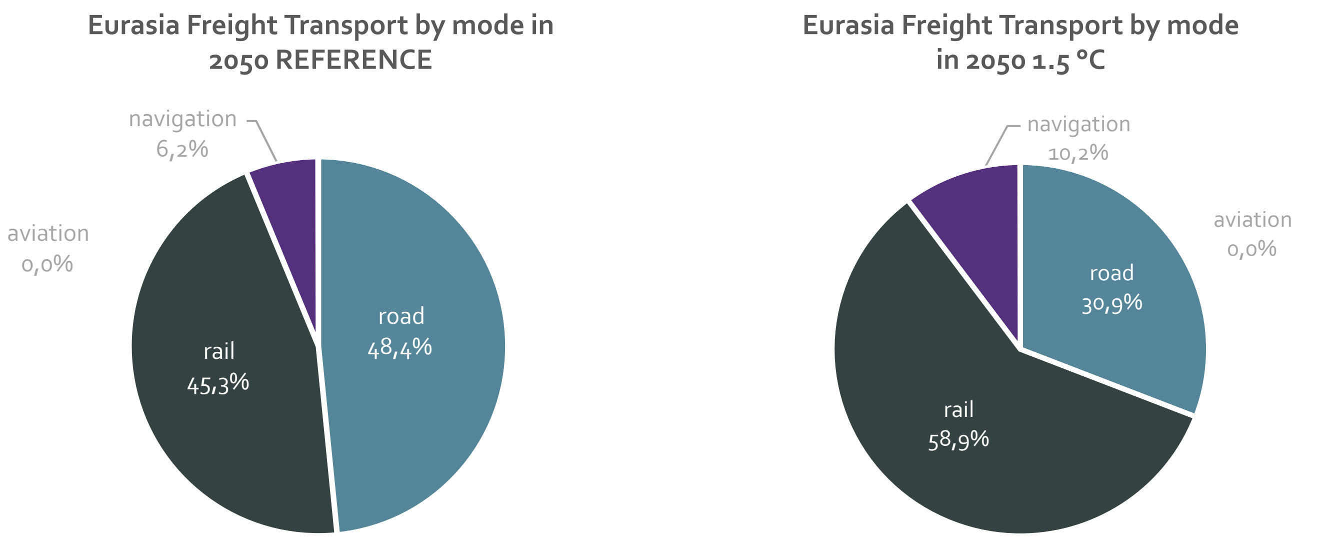


Figure 59. Eurasia: Development of freight transport under two scenarios by mode by 2050

Table 47. Eurasia: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	126%	146%	153%	161%
	2.0°C	100%	110%	141%	198%	230%	267%
	1.5°C	100%	129%	165%	232%	269%	312%
Road	REF	100%	165%	191%	233%	245%	257%
	2.0°C	100%	140%	162%	198%	218%	241%
	1.5°C	100%	138%	153%	169%	177%	186%
Domestic aviation	REF	100%	161%	211%	241%	253%	265%
	2.0°C	100%	131%	138%	149%	141%	135%
	1.5°C	100%	138%	125%	97%	83%	83%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	103%	108%	119%	125%	132%
	1.5°C	100%	104%	115%	140%	147%	154%
Total	REF	100%	154%	178%	215%	226%	237%
	2.0°C	100%	133%	157%	197%	219%	244%
	1.5°C	100%	136%	155%	181%	195%	211%

Table 48. Eurasia: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	117%	136%	166%	183%	202%
	2.0°C	100%	125%	156%	220%	255%	296%
	1.5°C	100%	125%	156%	220%	255%	296%
Road	REF	100%	172%	200%	243%	256%	269%
	2.0°C	100%	141%	164%	199%	220%	243%
	1.5°C	100%	140%	158%	175%	184%	193%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	102%	98%	91%	82%	74%
	1.5°C	100%	102%	92%	71%	61%	58%
Domestic navigation	REF	100%	106%	112%	117%	120%	123%
	2.0°C	100%	106%	117%	142%	157%	182%
	1.5°C	100%	109%	126%	169%	196%	228%
Total	REF	100%	138%	158%	191%	205%	220%
	2.0°C	100%	129%	155%	203%	230%	262%
	1.5°C	100%	129%	154%	196%	220%	247%

9.6.2. Development of transport services

Table 49. Eurasia: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	536	536	504	521	598	676
	2.0°C	536	536	523	586	661	733
	1.5°C	536	536	538	575	638	781
Road	REF	3,873	3,873	4,018	4,347	5,005	5,364
	2.0°C	3,873	3,873	3,307	3,311	2,512	2,417
	1.5°C	3,873	3,873	3,233	2,966	2,003	1,792
Domestic aviation	REF	232	232	301	364	396	425
	2.0°C	232	232	249	243	245	216
	1.5°C	232	232	261	220	162	135
Domestic navigation	REF	34	34	35	37	37	38
	2.0°C	34	34	35	38	45	55
	1.5°C	34	34	36	41	53	69
Total	REF	6,453	6,453	6,637	7,047	7,814	8,283
	2.0°C	6,453	6,453	5,555	5,474	3,787	3,420
	1.5°C	6,453	6,453	4,068	3,802	2,856	2,777

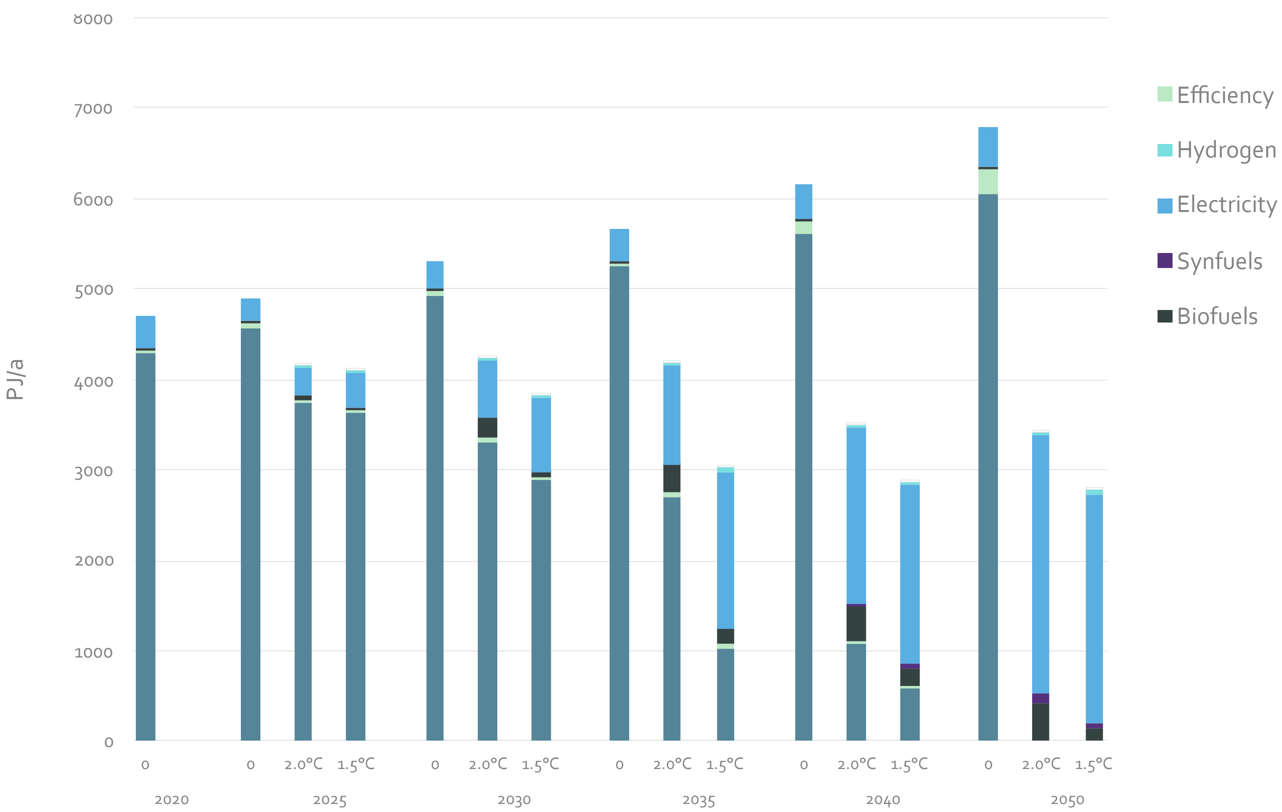
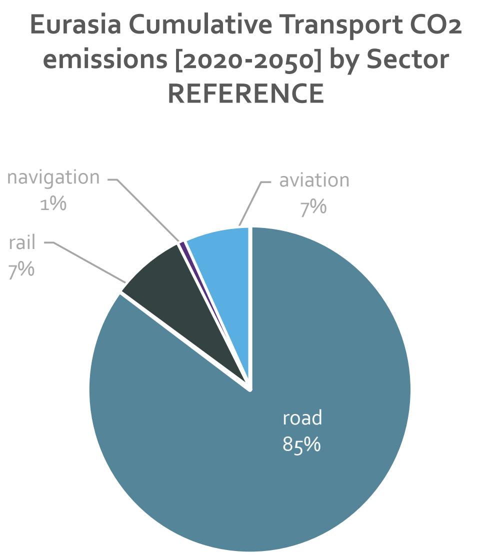


Figure 60. Eurasia: Final energy consumption transport under three scenarios

Table 50. Eurasia: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	65	63	36	29	23	24
	2.0°C	65	63	38	31	12	0
	1.5°C	65	63	38	28	5	0
Road	REF	292	292	301	323	367	390
	2.0°C	292	292	247	231	73	0
	1.5°C	292	292	241	204	53	0
Domestic aviation	REF	17	17	23	27	30	32
	2.0°C	17	17	19	18	11	0
	1.5°C	17	17	20	16	3	0
Domestic navigation	REF	3	3	3	3	3	3
	2.0°C	3	3	3	3	2	0
	1.5°C	3	3	3	3	1	0
Total	REF	377	375	362	382	422	448
	2.0°C	377	375	306	283	99	0
	1.5°C	377	375	302	251	62	0



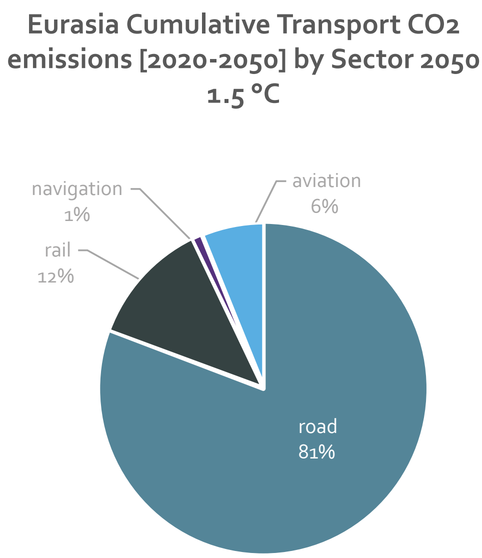


Figure 61. Eurasia: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 13 Gt CO_2

2.0°C: 6 Gt CO_2

1.5°C: 5 Gt CO_2

9.7. Non-OECD Asia

9.7.1. Development of transport demand

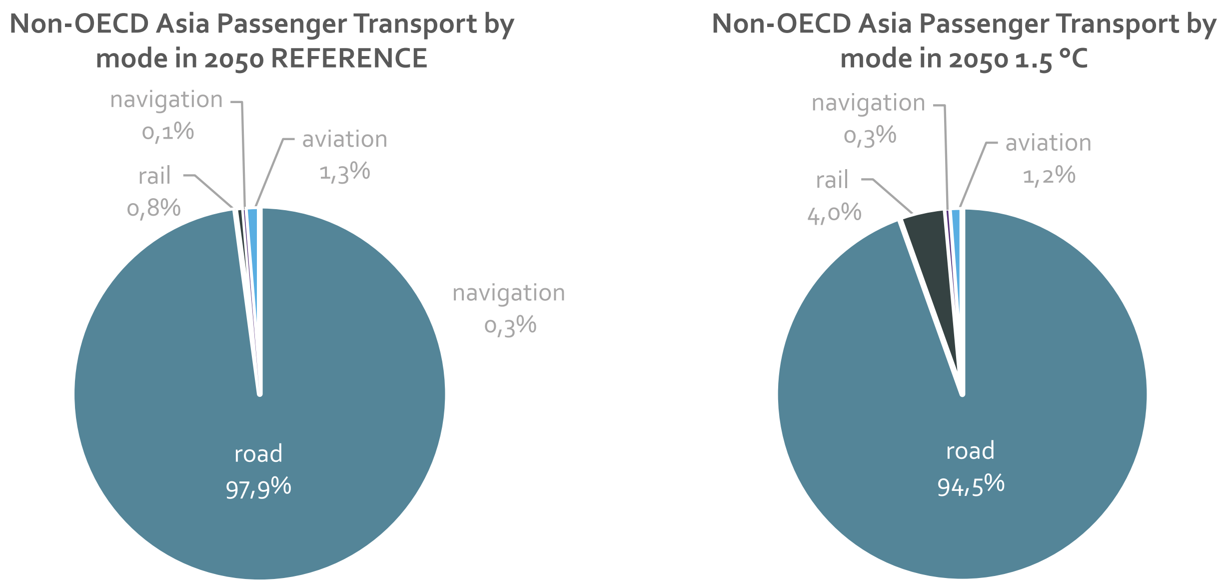


Figure 62. Non-OECD Asia: Development of passenger transport under two scenarios by mode by 2050

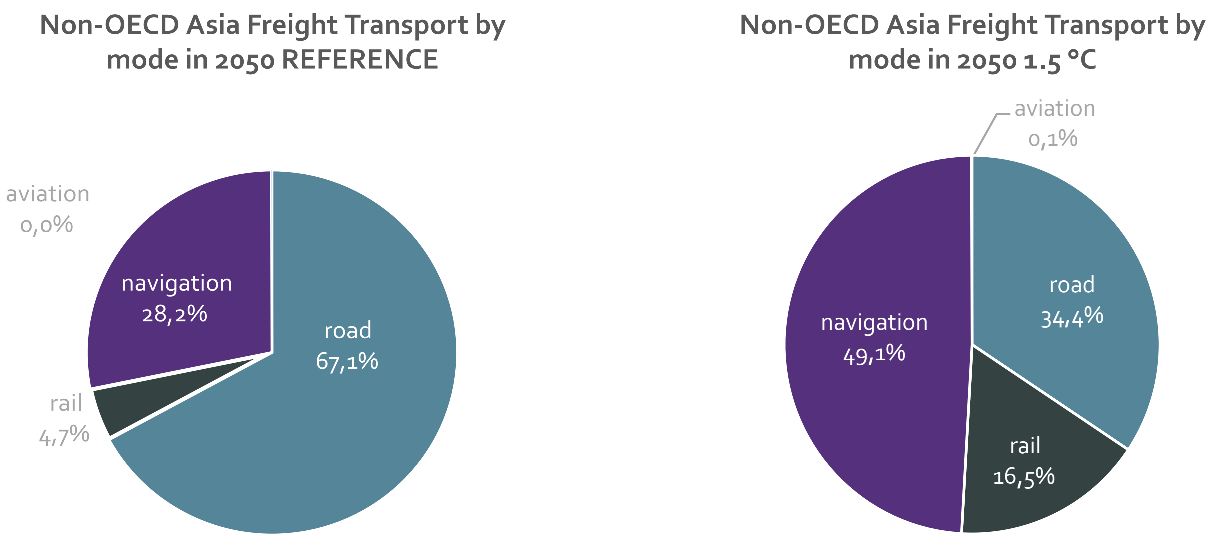


Figure 63. Non-OECD Asia: Development of freight transport under two scenarios by mode by 2050

Table 51. Non-OECD Asia: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	97%	156%	181%	190%	199%
	2.0°C	100%	96%	111%	164%	210%	268%
	1.5°C	100%	96%	122%	199%	254%	324%
Road	REF	100%	214%	273%	404%	446%	492%
	2.0°C	100%	168%	177%	195%	200%	205%
	1.5°C	100%	170%	178%	161%	154%	146%
Domestic aviation	REF	100%	126%	160%	237%	289%	351%
	2.0°C	100%	126%	123%	114%	108%	103%
	1.5°C	100%	126%	120%	108%	103%	98%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	104%	109%	121%	127%	133%
	1.5°C	100%	102%	107%	131%	144%	159%
Total	REF	100%	210%	268%	396%	438%	484%
	2.0°C	100%	166%	174%	193%	199%	204%
	1.5°C	100%	168%	176%	161%	154%	148%

Table 52. Non-OECD Asia: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	144%	167%	203%	225%	248%
	2.0°C	100%	113%	158%	257%	328%	419%
	1.5°C	100%	157%	253%	411%	525%	670%
Road	REF	100%	194%	225%	288%	318%	351%
	2.0°C	100%	158%	166%	183%	188%	192%
	1.5°C	100%	158%	166%	150%	143%	139%
Domestic aviation	REF	100%	112%	130%	174%	202%	234%
	2.0°C	100%	110%	113%	110%	99%	90%
	1.5°C	100%	110%	106%	98%	89%	80%
Domestic navigation	REF	100%	105%	111%	116%	119%	122%
	2.0°C	100%	103%	114%	139%	154%	170%
	1.5°C	100%	105%	111%	135%	149%	164%
Total	REF	100%	145%	163%	194%	210%	227%
	2.0°C	100%	127%	138%	163%	176%	190%
	1.5°C	100%	130%	141%	153%	162%	175%

9.7.2. Development of transport services

Table 53. Non-OECD Asia: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	41	41	80	84	75	85
	2.0°C	41	41	67	55	71	95
	1.5°C	41	41	71	69	97	142
Road	REF	6,023	6,023	6,708	7,778	10,486	12,377
	2.0°C	6,023	6,023	5,202	4,784	3,463	3,250
	1.5°C	6,023	6,023	5,173	4,691	2,670	1,984
Domestic aviation	REF	225	225	235	277	386	554
	2.0°C	225	225	234	214	189	166
	1.5°C	225	225	234	208	179	157
Domestic navigation	REF	197	197	202	209	213	219
	2.0°C	197	197	199	215	252	298
	1.5°C	197	197	202	209	246	292
Total	REF	6,486	6,486	7,225	8,347	11,159	13,235
	2.0°C	6,486	6,486	5,702	5,269	3,975	3,809
	1.5°C	6,486	6,486	5,680	5,177	3,191	2,575

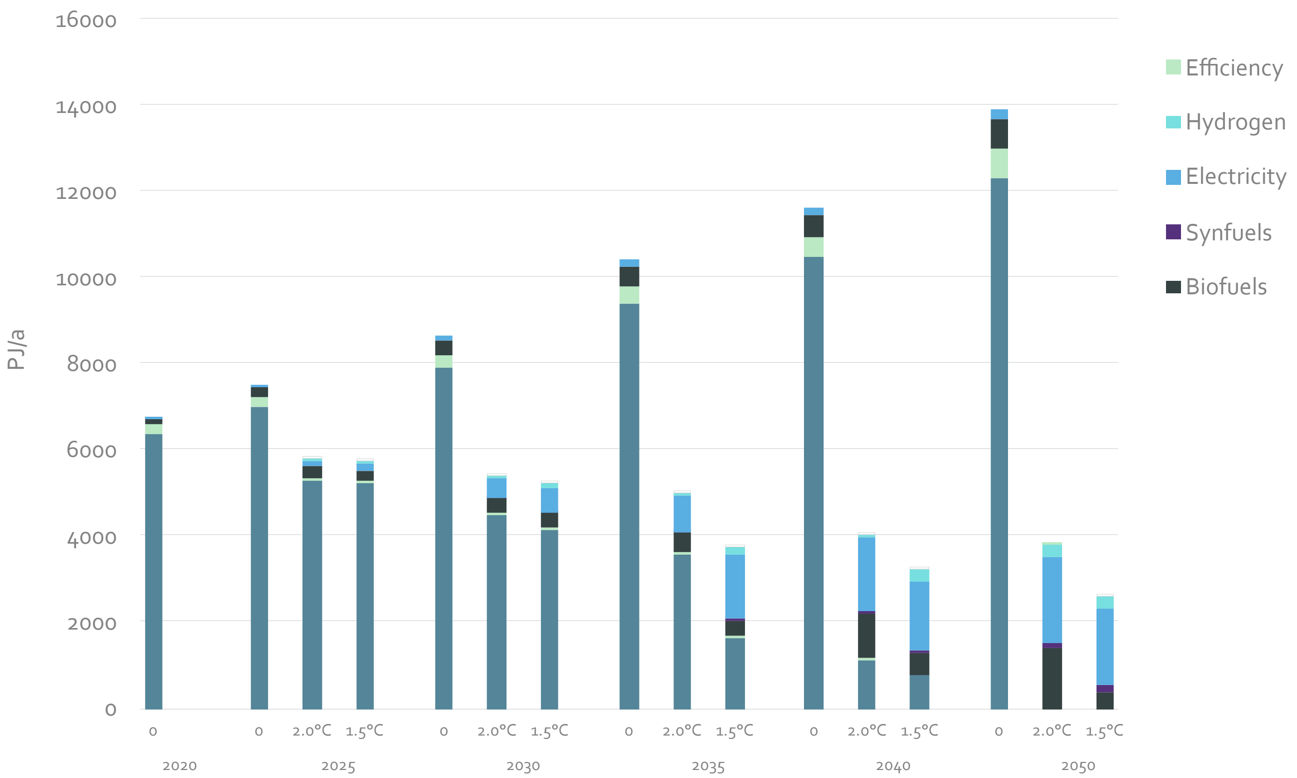
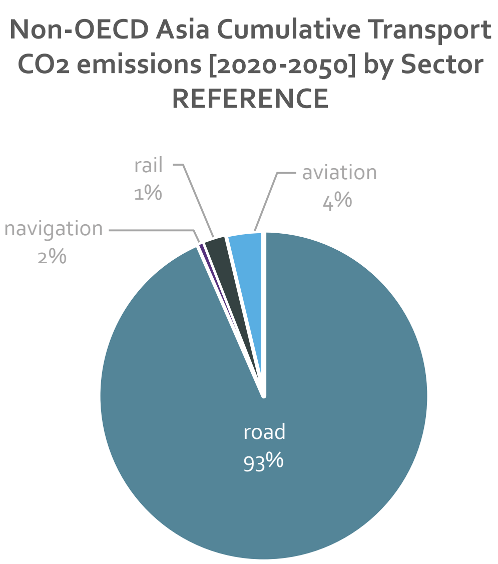


Figure 64. Non-OECD Asia: Final energy consumption transport under three scenarios

Table 54. Non-OECD Asia: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	4	4	6	5	3	3
	2.0°C	4	4	5	3	1	0
	1.5°C	4	4	5	3	1	0
Road	REF	463	462	501	566	737	849
	2.0°C	463	462	392	335	85	0
	1.5°C	463	462	388	321	69	0
Domestic aviation	REF	17	17	18	21	29	42
	2.0°C	17	17	18	16	9	0
	1.5°C	17	17	18	15	3	0
Domestic navigation	REF	15	15	15	16	16	16
	2.0°C	15	15	15	16	12	0
	1.5°C	15	15	15	14	4	0
Total	REF	498	498	540	608	785	910
	2.0°C	498	498	429	369	107	0
	1.5°C	498	498	426	353	77	0



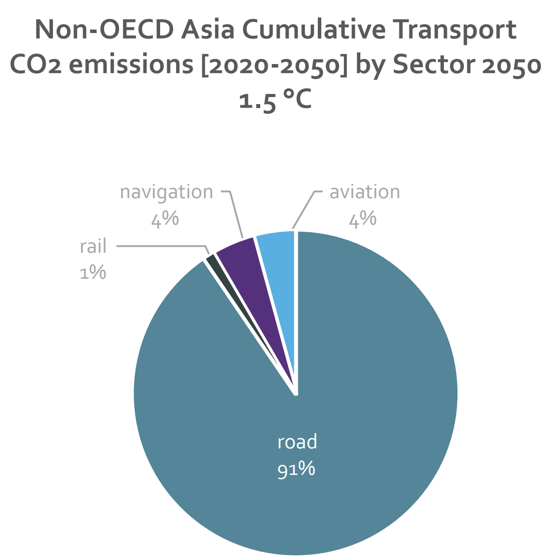


Figure 65. Non-OECD Asia: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 22 Gt CO_2

2.0°C: 10 Gt CO_2

1.5°C: 8 Gt CO_2

9.8. India

9.8.1. Development of transport demand

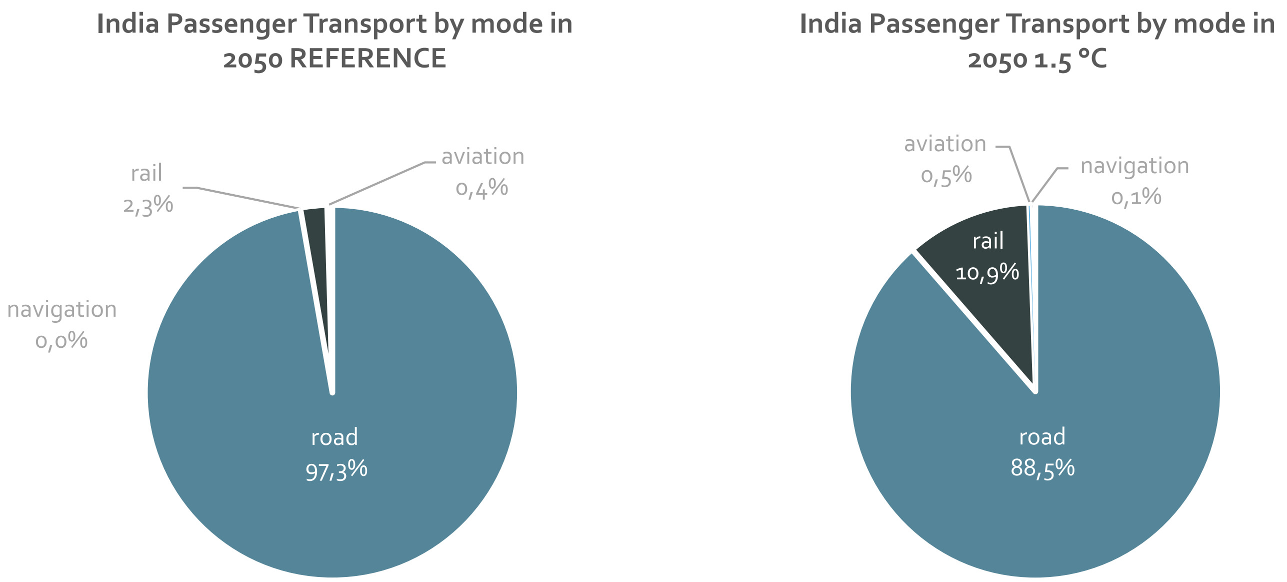


Figure 66. India: Development of passenger transport under two scenarios by mode by 2050

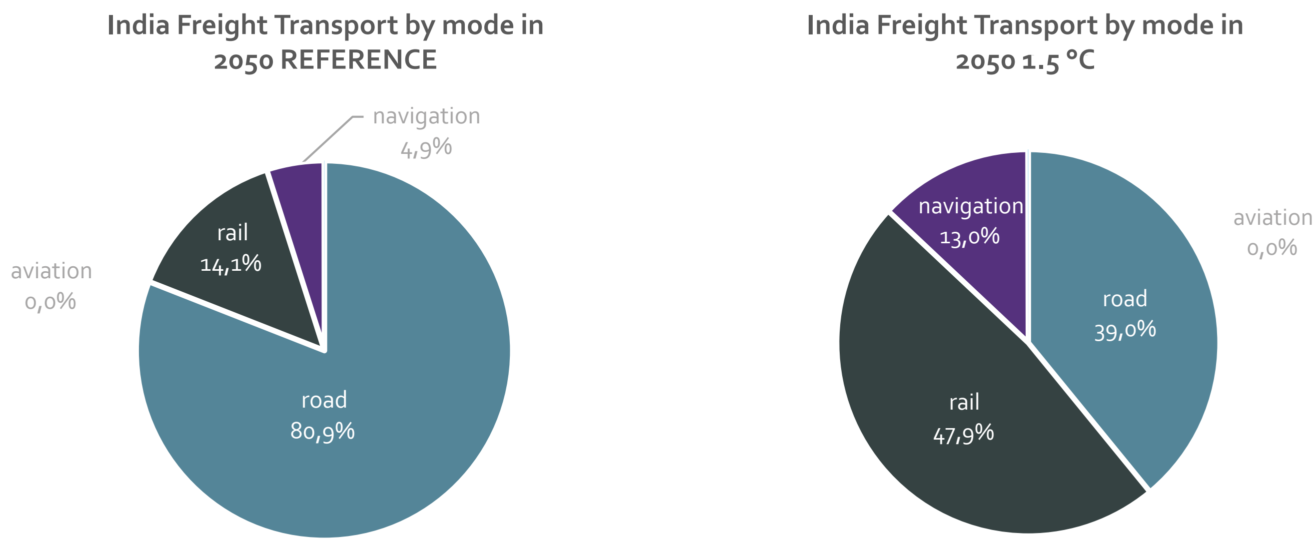


Figure 67. India: Development of freight transport under two scenarios by mode by 2050

Table 55. India: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	130%	151%	203%	235%	272%
	2.0°C	100%	115%	146%	239%	304%	389%
	1.5°C	100%	110%	141%	277%	329%	391%
Road	REF	100%	149%	204%	384%	526%	720%
	2.0°C	100%	120%	153%	250%	290%	336%
	1.5°C	100%	116%	134%	180%	189%	199%
Domestic aviation	REF	100%	120%	154%	250%	320%	389%
	2.0°C	100%	105%	116%	141%	149%	152%
	1.5°C	100%	106%	112%	120%	126%	133%
Domestic navigation	REF	100%	114%	145%	177%	195%	216%
	2.0°C	100%	110%	141%	229%	293%	374%
	1.5°C	100%	114%	145%	236%	302%	385%
Total	REF	100%	148%	201%	372%	507%	691%
	2.0°C	100%	120%	153%	248%	289%	337%
	1.5°C	100%	115%	134%	185%	197%	210%

Table 56. India: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	140%	179%	292%	338%	392%
	2.0°C	100%	130%	166%	271%	345%	441%
	1.5°C	100%	130%	166%	327%	458%	643%
Road	REF	100%	156%	211%	386%	523%	708%
	2.0°C	100%	117%	129%	157%	173%	192%
	1.5°C	100%	117%	129%	150%	157%	165%
Domestic aviation	REF	100%	110%	141%	229%	293%	374%
	2.0°C	100%	104%	112%	130%	137%	144%
	1.5°C	100%	104%	109%	121%	127%	133%
Domestic navigation	REF	100%	115%	133%	162%	179%	198%
	2.0°C	100%	106%	123%	149%	165%	182%
	1.5°C	100%	115%	147%	206%	228%	252%
Total	REF	100%	147%	193%	335%	436%	570%
	2.0°C	100%	118%	136%	179%	208%	241%
	1.5°C	100%	119%	139%	194%	229%	276%

9.8.2. Development of transport services

Table 57. India: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	180	180	150	178	260	337
	2.0°C	180	180	147	166	218	292
	1.5°C	180	180	132	141	236	378
Road	REF	3,294	3,294	4,013	5,113	9,001	16,260
	2.0°C	3,294	3,294	3,098	3,275	3,017	3,153
	1.5°C	3,294	3,294	2,976	2,839	2,383	2,065
Domestic aviation	REF	84	84	84	100	154	236
	2.0°C	84	84	74	76	87	92
	1.5°C	84	84	74	73	75	81
Domestic navigation	REF	29	29	33	38	45	53
	2.0°C	29	29	30	35	43	52
	1.5°C	29	29	33	41	57	70
Total	REF	3,602	3,602	4,280	5,429	9,460	16,885
	2.0°C	3,602	3,602	3,349	3,553	3,364	3,590
	1.5°C	3,602	3,602	3,216	3,094	2,750	2,594

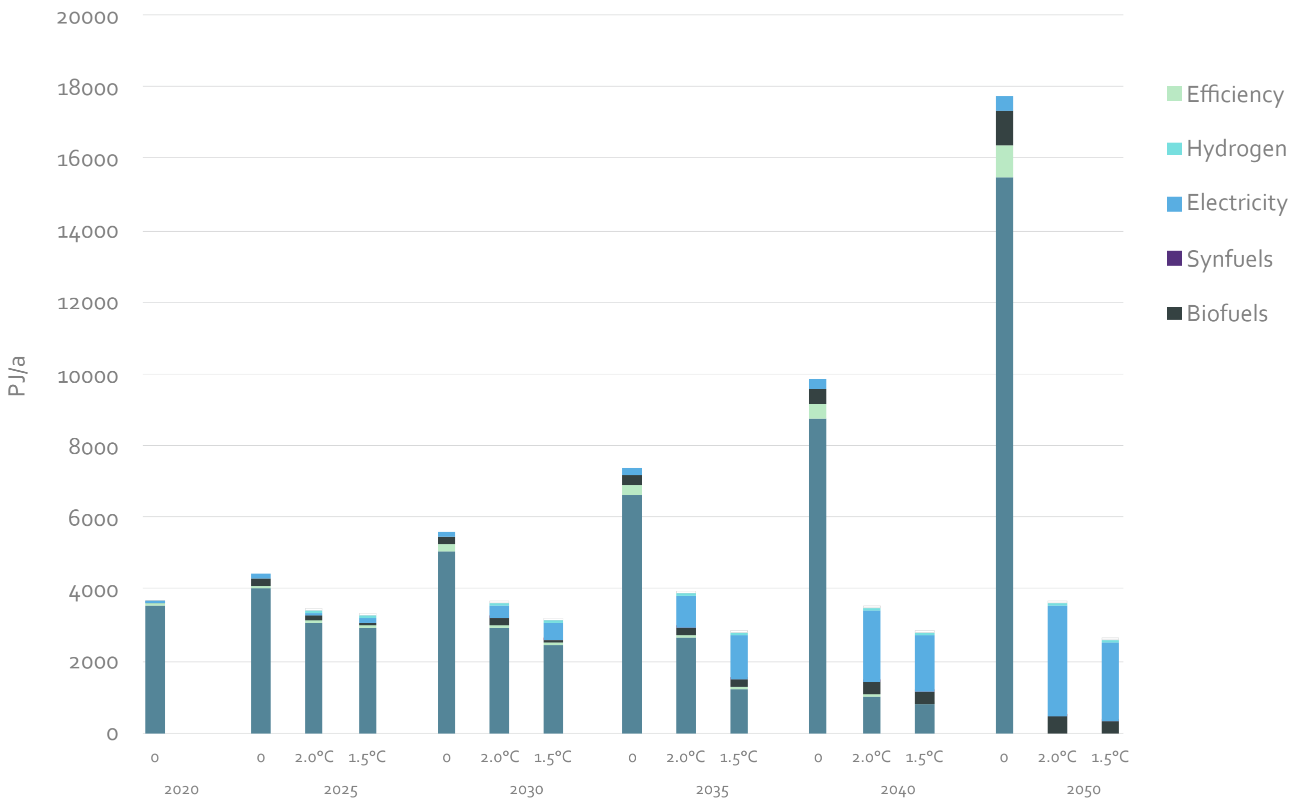
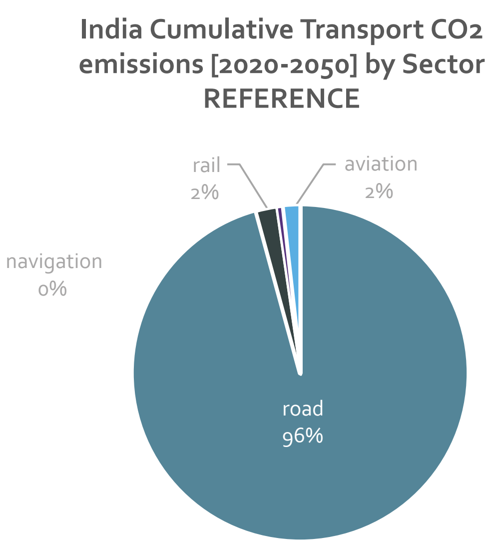


Figure 68. India: Final energy consumption transport under three scenarios

Table 58. India: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	18	17	11	10	10	12
	2.0°C	18	17	11	9	4	0
	1.5°C	18	17	9	7	2	0
Road	REF	247	247	301	372	632	1,114
	2.0°C	247	247	232	228	83	0
	1.5°C	247	247	223	194	71	0
Domestic aviation	REF	6	6	6	7	12	18
	2.0°C	6	6	6	6	4	0
	1.5°C	6	6	6	5	1	0
Domestic navigation	REF	2	2	2	3	3	4
	2.0°C	2	2	2	3	2	0
	1.5°C	2	2	2	3	1	0
Total	REF	273	273	320	392	657	1,147
	2.0°C	273	273	251	245	93	0
	1.5°C	273	273	240	209	75	0



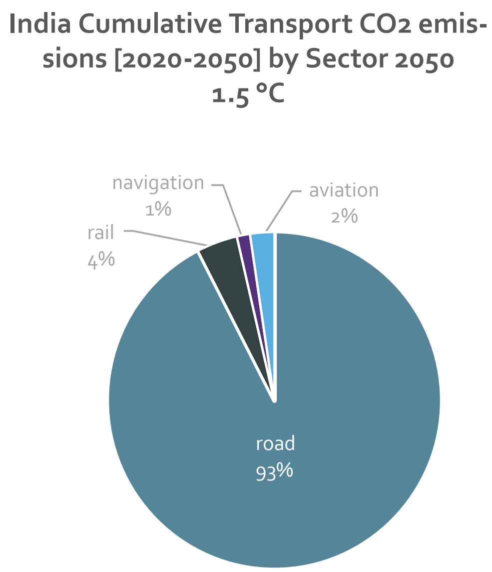


Figure 69. India: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 18 Gt CO_2

2.0°C: 5 Gt CO_2

1.5°C: 4 Gt CO_2

9.9. China

9.9.1. Development of transport demand

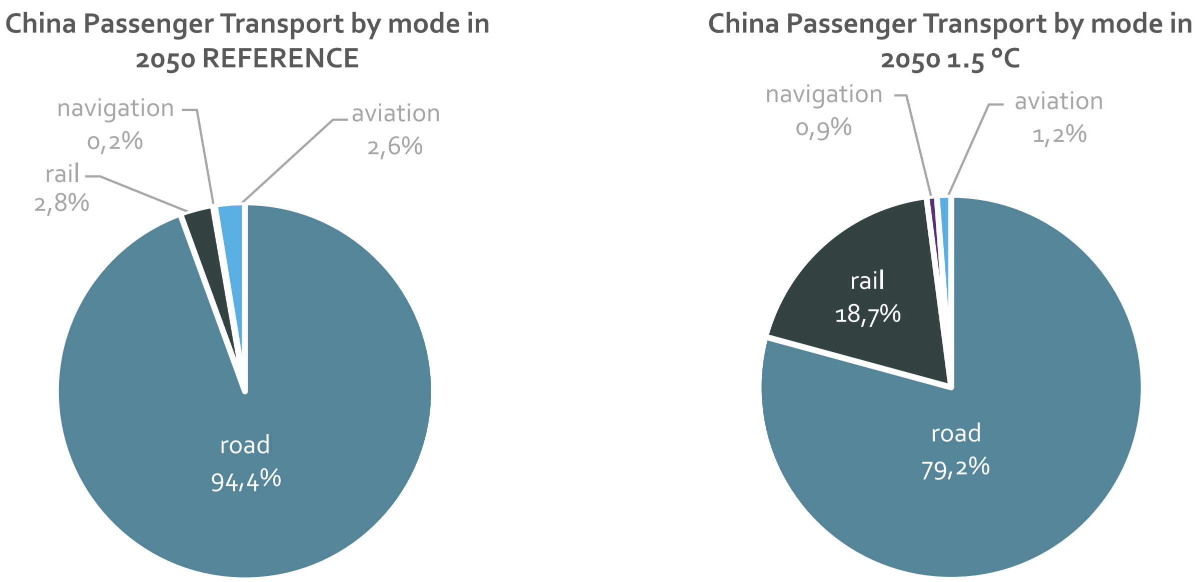


Figure 70. China: Development of passenger transport under two scenarios by mode by 2050

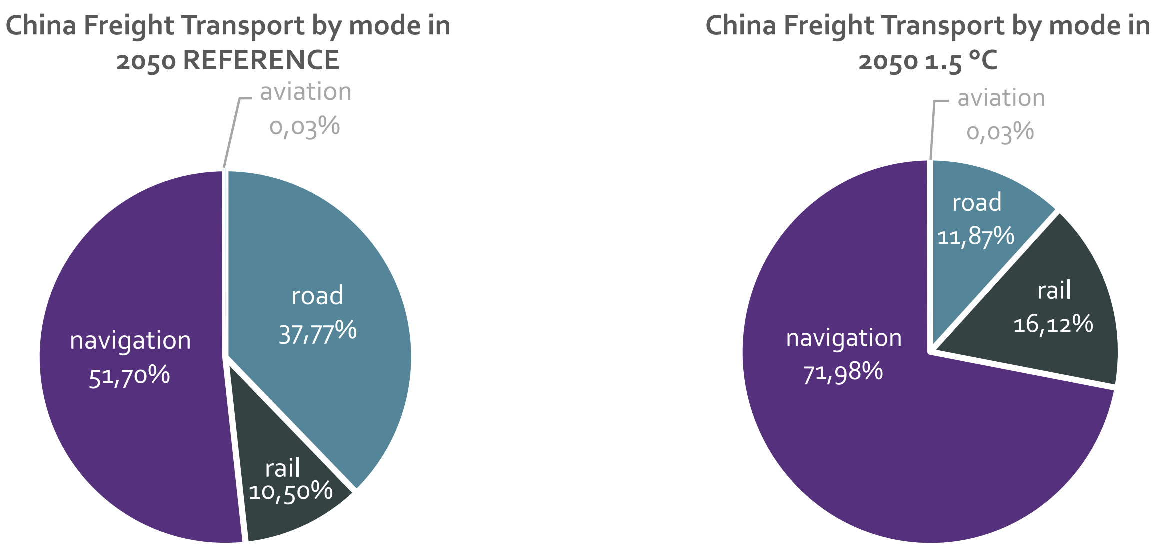


Figure 71. China: Development of freight transport under two scenarios by mode by 2050

Table 59. China: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	126%	146%	153%	161%
	2.0°C	100%	129%	165%	232%	269%	312%
	1.5°C	100%	134%	188%	253%	286%	323%
Road	REF	100%	136%	174%	257%	298%	337%
	2.0°C	100%	108%	114%	123%	117%	111%
	1.5°C	100%	108%	120%	105%	95%	86%
Domestic aviation	REF	100%	115%	146%	239%	304%	389%
	2.0°C	100%	101%	107%	96%	92%	87%
	1.5°C	100%	101%	96%	75%	64%	55%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	106%	112%	121%	127%	133%
	1.5°C	100%	103%	125%	176%	194%	204%
Total	REF	100%	134%	170%	250%	289%	327%
	2.0°C	100%	109%	117%	128%	125%	122%
	1.5°C	100%	110%	123%	114%	106%	100%

Table 60. China: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	117%	136%	166%	183%	202%
	2.0°C	100%	125%	156%	220%	255%	296%
	1.5°C	100%	130%	183%	234%	264%	299%
Road	REF	100%	138%	153%	186%	205%	227%
	2.0°C	100%	108%	114%	123%	117%	105%
	1.5°C	100%	108%	103%	93%	80%	69%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	106%	112%	103%	94%	85%
	1.5°C	100%	102%	98%	76%	65%	56%
Domestic navigation	REF	100%	106%	117%	136%	143%	150%
	2.0°C	100%	109%	127%	143%	147%	151%
	1.5°C	100%	106%	123%	165%	183%	202%
Total	REF	100%	117%	129%	154%	165%	178%
	2.0°C	100%	109%	123%	150%	160%	171%
	1.5°C	100%	110%	126%	144%	148%	151%

9.9.2. Development of transport services

Table 61. China: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	539	539	556	441	507	574
	2.0°C	539	539	616	531	596	661
	1.5°C	539	539	640	525	581	676
Road	REF	10,421	10,421	11,344	12,972	17,317	21,616
	2.0°C	10,421	10,421	8,941	8,175	5,803	4,141
	1.5°C	10,421	10,421	8,867	7,959	4,420	3,041
Domestic aviation	REF	754	754	717	846	1,274	1,987
	2.0°C	754	754	645	632	544	476
	1.5°C	754	754	642	570	420	303
Domestic navigation	REF	877	877	908	984	1,099	1,183
	2.0°C	877	877	936	1,060	1,157	1,189
	1.5°C	877	877	908	1,040	1,357	1,606
Total	REF	12,604	12,604	13,525	15,243	20,197	25,361
	2.0°C	12,604	12,604	11,137	10,398	8,101	6,467
	1.5°C	12,604	12,604	11,057	10,094	6,778	5,626

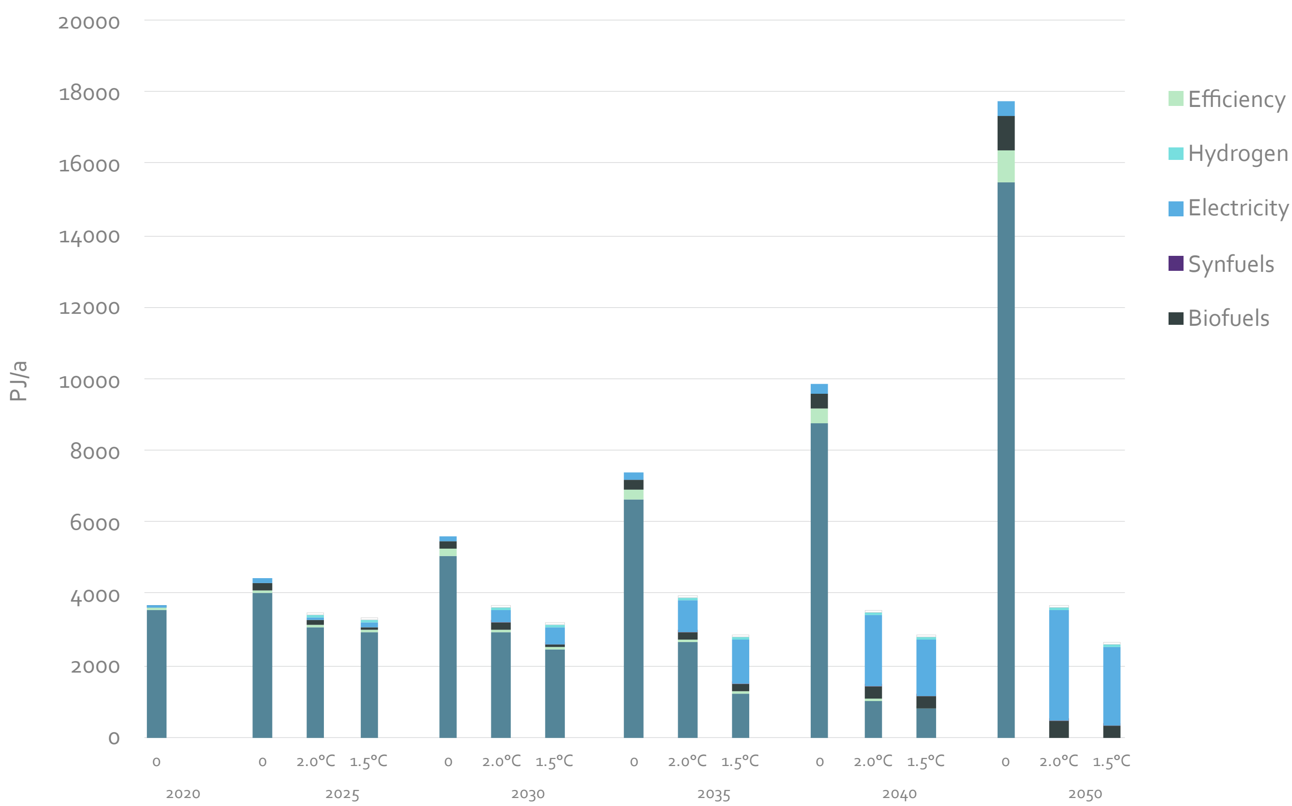
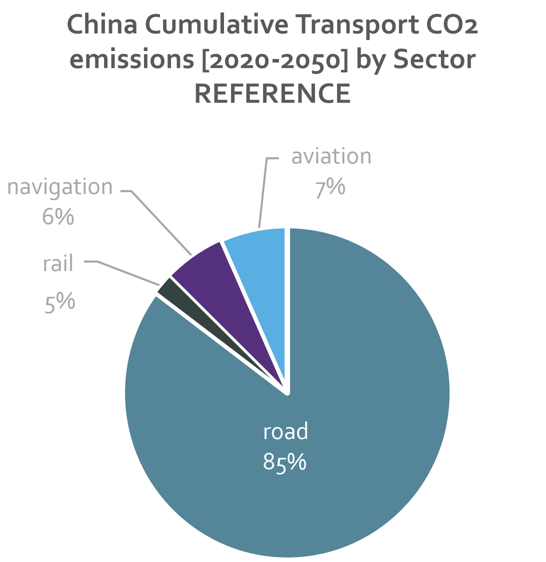


Figure 72. China: Final energy consumption transport under three scenarios

Table 62. China: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	55	54	41	24	20	20
	2.0°C	55	54	45	28	11	0
	1.5°C	55	54	47	24	5	0
Road	REF	806	804	835	940	1,208	1,472
	2.0°C	806	804	658	564	172	0
	1.5°C	806	804	651	535	88	0
Domestic aviation	REF	57	57	54	63	96	149
	2.0°C	57	57	49	46	25	0
	1.5°C	57	57	48	42	7	0
Domestic navigation	REF	66	66	68	74	82	89
	2.0°C	66	66	70	77	53	0
	1.5°C	66	66	68	70	25	0
Total	REF	984	981	998	1,101	1,406	1,730
	2.0°C	984	981	822	716	261	0
	1.5°C	984	981	815	670	125	0



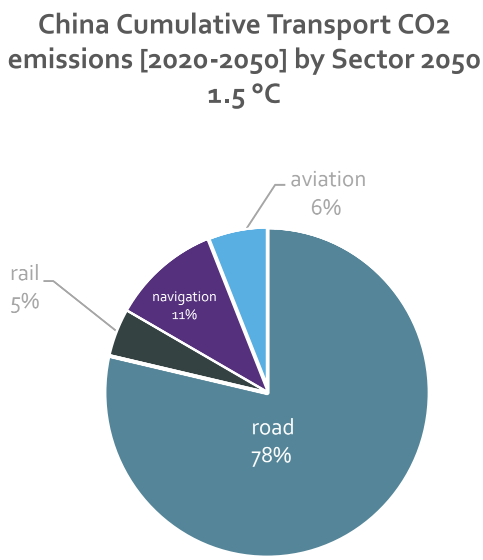


Figure 73. China: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 40 Gt CO_2

2.0°C: 15 Gt CO_2

1.5°C: 13 Gt CO_2

9.10. OECD Pacific

9.10.1. Development of transport demand

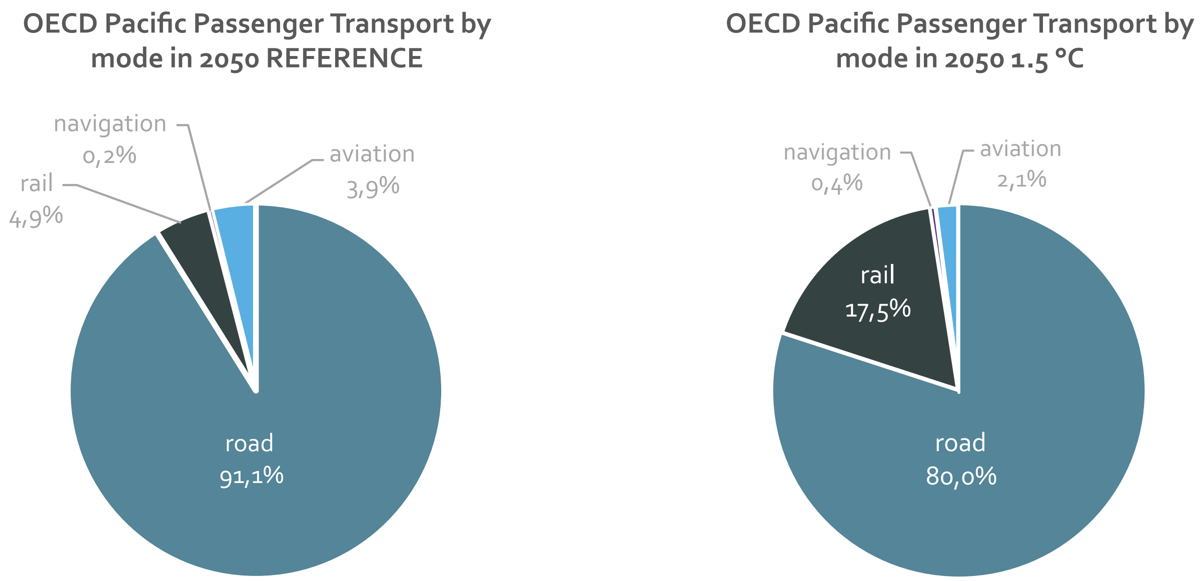


Figure 74. OECD Pacific: Development of passenger transport under two scenarios by mode by 2050

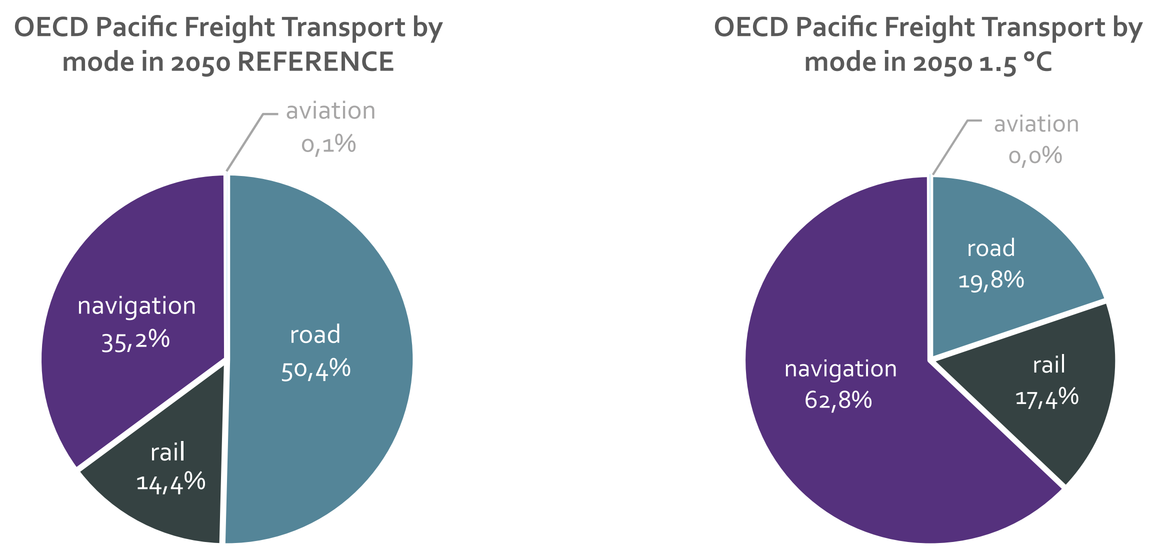


Figure 75. OECD Pacific: Development of freight transport under two scenarios by mode by 2050

Table 63. OECD Pacific: Development of passenger travel behavior change - based on passenger kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	114%	126%	146%	153%	161%
	2.0°C	100%	110%	134%	189%	220%	255%
	1.5°C	100%	134%	188%	253%	286%	323%
Road	REF	100%	113%	118%	121%	122%	122%
	2.0°C	100%	109%	104%	79%	75%	68%
	1.5°C	100%	107%	92%	73%	66%	60%
Domestic aviation	REF	100%	161%	211%	241%	253%	265%
	2.0°C	100%	101%	98%	94%	91%	89%
	1.5°C	100%	101%	96%	87%	83%	79%
Domestic navigation	REF	100%	102%	107%	116%	122%	128%
	2.0°C	100%	104%	109%	133%	146%	162%
	1.5°C	100%	103%	113%	138%	152%	168%
Total	REF	100%	114%	120%	124%	126%	126%
	2.0°C	100%	109%	105%	83%	81%	75%
	1.5°C	100%	108%	95%	80%	75%	70%

Table 64. OECD Pacific: Development of freight logistics change - based on ton kilometer by transport mode

		2020	2025	2030	2040	2045	2050
Rail	REF	100%	117%	136%	166%	183%	202%
	2.0°C	100%	125%	156%	220%	255%	296%
	1.5°C	100%	130%	183%	234%	264%	299%
Road	REF	100%	106%	112%	123%	130%	136%
	2.0°C	100%	103%	98%	95%	86%	82%
	1.5°C	100%	103%	98%	89%	76%	65%
Domestic aviation	REF	100%	102%	119%	138%	145%	151%
	2.0°C	100%	103%	99%	92%	90%	87%
	1.5°C	100%	102%	98%	76%	65%	56%
Domestic navigation	REF	100%	106%	112%	117%	120%	123%
	2.0°C	100%	104%	127%	187%	217%	252%
	1.5°C	100%	106%	136%	201%	233%	270%
Total	REF	100%	107%	114%	125%	131%	138%
	2.0°C	100%	106%	115%	144%	154%	170%
	1.5°C	100%	107%	121%	147%	156%	168%

9.10.2. Development of transport services

Table 65. OECD Pacific: Projection of transport energy demand by sector in [PJ/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	158	158	159	146	168	190
	2.0°C	158	158	163	162	183	203
	1.5°C	158	158	166	174	193	225
Road	REF	5,515	5,515	4,924	4,828	4,779	4,796
	2.0°C	5,515	5,515	4,677	3,839	2,054	1,340
	1.5°C	5,515	5,515	4,535	3,360	1,691	1,138
Domestic aviation	REF	331	331	430	520	565	607
	2.0°C	331	331	281	255	229	213
	1.5°C	331	331	282	250	211	184
Domestic navigation	REF	173	173	179	185	189	194
	2.0°C	173	173	176	209	295	384
	1.5°C	173	173	179	223	316	411
Total	REF	6,186	6,186	5,693	5,680	5,701	5,788
	2.0°C	6,186	6,186	5,297	4,464	2,761	2,140
	1.5°C	6,186	6,186	5,161	4,008	2,411	1,957

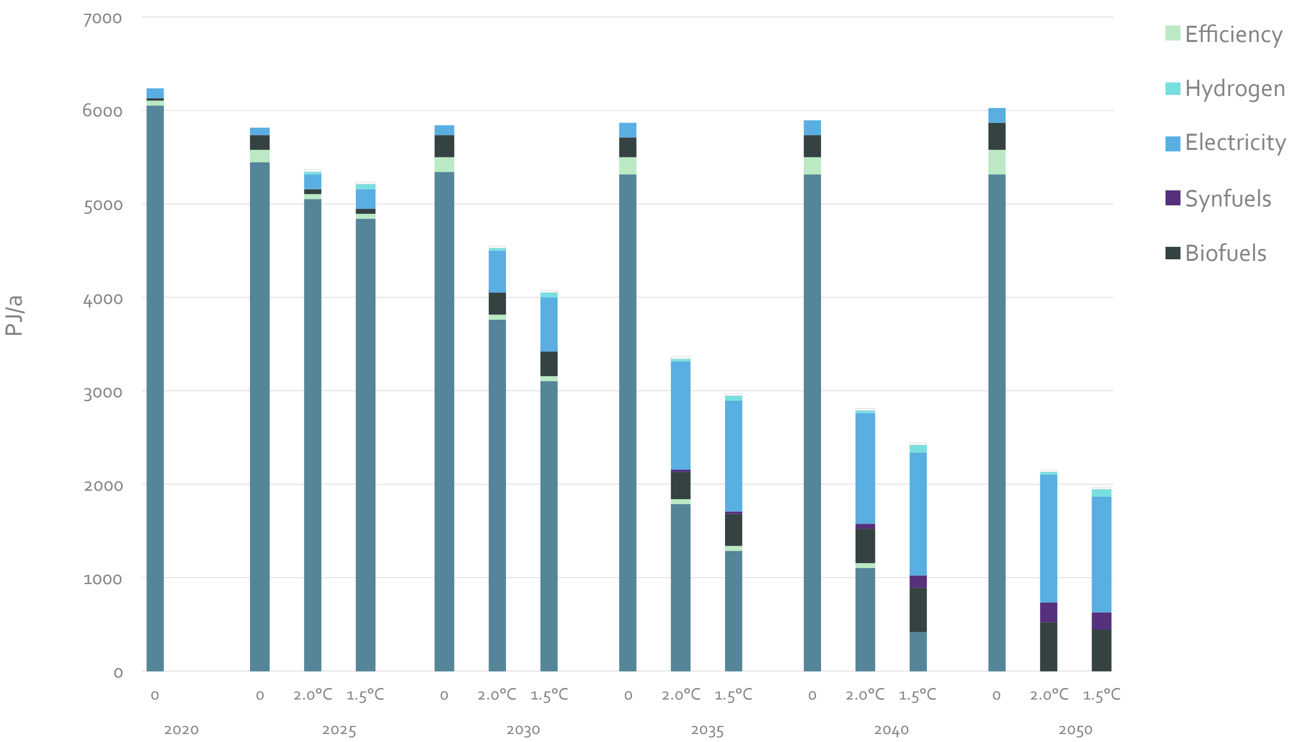
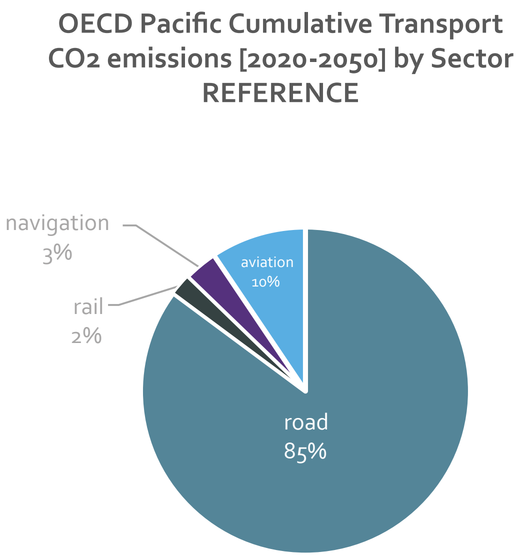


Figure 76. OECD Pacific: Final energy consumption transport under three scenarios

Table 66. OECD Pacific: CO_2 emission by transport sector in [million-ton CO_2/a]

		2019	2020	2025	2030	2040	2050
Rail	REF	18	18	12	8	7	7
	2.0°C	18	18	12	9	3	0
	1.5°C	18	18	12	8	2	0
Road	REF	416	416	369	352	336	328
	2.0°C	416	416	349	268	69	0
	1.5°C	416	416	338	229	36	0
Domestic aviation	REF	25	25	32	39	42	46
	2.0°C	25	25	21	19	10	0
	1.5°C	25	25	21	18	3	0
Domestic navigation	REF	13	13	13	14	14	15
	2.0°C	13	13	13	15	13	0
	1.5°C	13	13	14	15	6	0
Total	REF	472	471	426	413	399	395
	2.0°C	472	471	396	310	96	0
	1.5°C	472	471	385	270	47	0



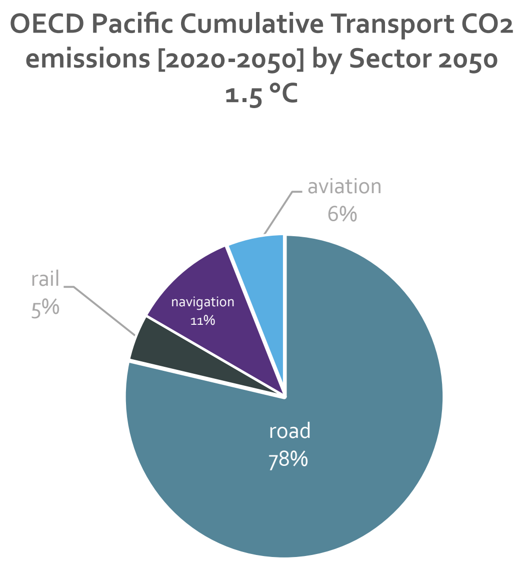


Figure 77. OECD Pacific: Cumulative CO_2 Transport Emissions [2020-2050]

REFERENCE: 40 Gt CO_2

2.0°C: 15 Gt CO_2

1.5°C: 13 Gt CO_2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