PATHWAYS TO DEEP DECARBONIZATION

of the passenger transport sector

IN JAPAN

Mikiko Kainuma, *NIES/IGES*
Toshihiko Masui, *NIES*
Ken Oshiro, *MHIR*
Runsen Zhang, *NIES*

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THE TRANSPORT DEEP DECARBONIZATION PATHWAYS PROJECT (DDPP-T)

The Transport Deep Decarbonization Pathways Project (DDPP-T), an initiative of the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their transport system by 2050 in order to implement a deep reduction in their greenhouse gas emissions, consistent with ambitious climate goals.The DDPP-T builds on the Deep Decarbonization Pathways Project (DDPP), which analyzed the deep decarbonization of energy systems in 16 countries in the lead-up to COP21. The two projects share key principles. The analysis is conducted at a country scale, by in-country research teams, working independently of their governments. It adopts a 2050 time horizon to reveal the short-term requirements of long-term climate and development objectives. Finally, country research teams openly share methods, modelling tools, data and results in order to enable knowledge sharing among project partners in a highly collaborative way and to facilitate engagement with sectoral experts and decision makers.

Contact information for this country report

Mikiko Kainuma, mikiko@nies.go.jp
Toshihiko Masui, masui@nies.go.jp
Ken Oshiro, ken.oshiro@mizuho-ir.co.jp
Runsen Zhang, zhang.runsen@nies.go.jp

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Foreword

This analysis considers passenger transport, encompassing the mobility of resident citizens including domestic and international air flights and non-motorized travel. Freight transport will be considered in future work.

The analysis starts from an acknowledgment that profound transformations of the passenger transport sector, that could deliver deep greenhouse gas emission reductions consistent with an ambitious climate goal, go beyond technological change. They require considering a more systemic approach to build decarbonization storylines, including key drivers like the evolution of demographic and economic situation, individual behaviours, lifestyles, infrastructures and spatial organization. The approach also recognizes the need to provide quantification of these storylines for key indicators characterizing mobility patterns such as distances travelled by trip purposes, by location of people, by modes or budget and time dedicated to transport activities. The methodology of the DDPP-T, adopted by all country research teams in the project, connects these two complementary approaches to long-term deep decarbonization analysis of the transport sector consistent with emission reductions computed in previous DDPP national scenarios..

The structure of the report reflects this approach. The key determinants of mobility are described by the storylines in the second section. These storylines are then translated into a quantitative sector-wide representation of the transport sector, which form the core of the third section. Finally, a sub-set of these indicators have been chosen as key quantitative metrics to engage stakeholders and decision makers, and are presented in the Annex.

PATHWAYS TO DEEP DECARBONIZATION
OF THE PASSENGER TRANSPORT SECTOR IN JAPAN

Executive summary

The passenger transport sector accounted for 12% of Japan's CO_2 emissions in 2010, which is known as one of the main cause of global warming. Transport-related energy use and emissions could increase at a faster rate than emissions from the energy end-use sectors without the implementation of aggressive and sustained policy interventions. Because the continuing growth in traffic activities could outweigh all mitigation measures unless transport emissions can be strongly decoupled from GDP growth, it will be challenging to reduce the passenger transport-related emissions to achieve the goal of deep decarbonization in Japan.

Two Deep Decarbonization Pathways Project (DDPP) scenarios are structured to investigate the way in which different technical and social transformations can reduce the transport-related energy use and GHG emissions. An advanced technological (AdvancedTech) scenario focuses mainly on the technological innovations and transformations in the transport and energy sector, but does not give consideration to social and behavioural factors. The GHG emission reduction target under continued economic growth is achieved by large-scale energy demand reduction by end users and decarbonization of power generation. On the other hand, the balanced scenario is structured with the objective of developing a long-term strategy to achieve a drastic GHG emission reduction in transport sector by means of a balanced behavioural and technological changes. Compared with the focus of technological development in the AdvancedTech scenario, the balanced scenario is aimed to explore the maximum reduction potential of GHG emissions from an integrated and combined perspective of both technological innovation and social transformations.

In the AdvancedTech scenario, although the average annual distance travelled per capita increases during 2010 to 2050, the average individual emissions from passenger transport decrease over this period, thanks to the improvement of energy efficiency and emissions intensity. The large electrification in transport sector is the main contributor of emission reduction, followed by the strong decarbonization in the power generation sector through a massive deployment of CCS and renewable energies. The share of renewable energies and CCS-equipped plants reaches high proportions of total electricity generation, thus the GHG emissions in transport sector can be largely reduced by the shift to low-carbon electricity. In the balanced scenario, the emission trajectory shows much lower values than those of the AdvancedTech scenario, thanks to the decreasing individual mobility and modal shift from carbon-intensive modes towards low-carbon modes of transport. Social and behavioural changes in demography, urban structures, land use, lifestyle, infrastructure can effectively contribute to further reduce the GHG emissions above the technological transformations.

A roadmap for moving to a deep decarbonized transport sector is presented by combining low-carbon policy initiatives and measures in consideration of both technological and social transformations such as environmentally-friendly vehicle technologies, CCS-equipped power plants, compact city, mixed and intensified land use, transit-oriented development, pedestrian-friendly street design, lifestyle change, and so forth. In order to alleviate the risks that the deep decarbonization pathway fails and the targets are not achieved as planned, it is necessary to consider which policies are the first priorities for the near future. Since the deep electrification and CCS deployment cannot be achieved in the short-term, the efficiency improvements in conventional internal combustion engine-driven vehicles and aircraft deserve more attentions in the near-term. Social transformations such as low-carbon urban reorganization, teleworking, online shopping also can be effective within a short period.

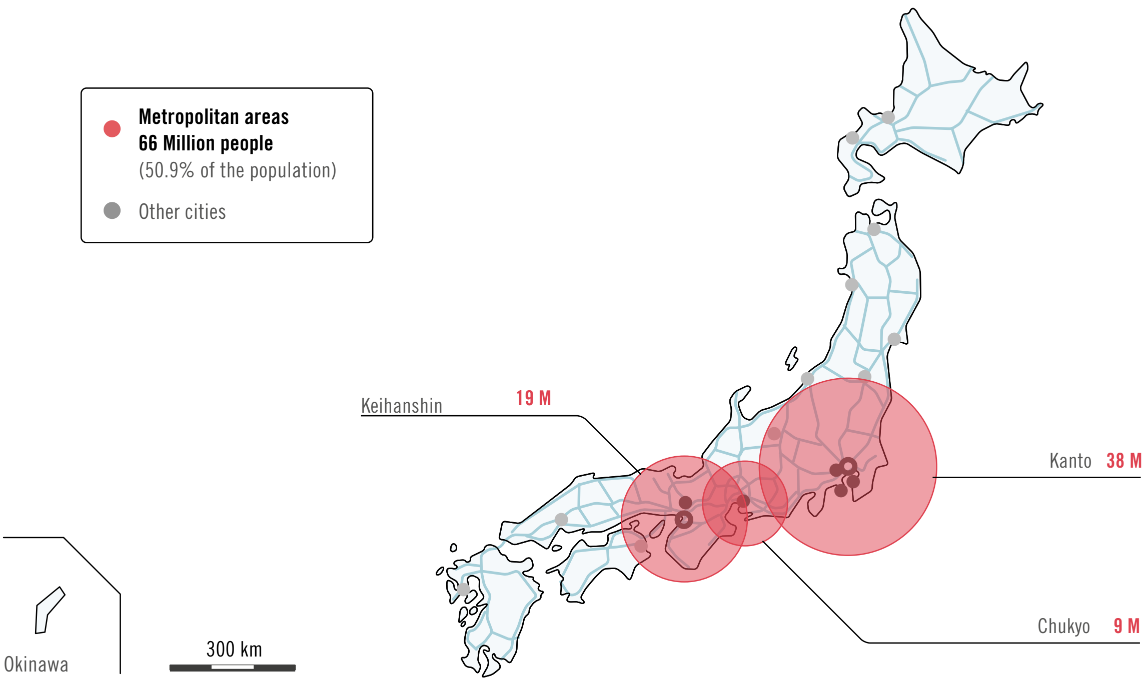
Description of the passenger transport sector

Situation and key features in 2010

Passenger transport demand was 1,370 Gpkm in 2010 and is dominated by road transport.
In 2010 the total population of Japan was 128 million and the passenger transport demand per capita was about 10.7 Kpkm/capita (excluding non-motorized mobility). Private and commercial vehicles covered about 60% of this total mobility, followed by trains, buses and aviation (IEEJ, 2016). Public transport (bus + train) covered about a third of passenger transport in 2010.

In 2010 private car use was the dominant mode of travel in rural areas, while public transportation was the most used type of mobility in metropolitan areas.
In rural areas, private cars and two-wheelers represented over 80% of passenger transport demand on weekdays. By contrast, in the central metropolitan area (Tokyo, Nagoya and Osaka) public transport served about a third of the transport demand (MLIT, 2012). With more details, in centres of metropolitan areas, about 60% of commuting is covered by public transport, whereas private car use is dominant (> 80%) in rural area (MLIT, 2012).

Figure 1. Schematic view of Japan, metropolitan areas, largest cities and main road network in 2010



Definition: country team defined the perimeter of metropolitan areas based on a per capita basis, population density and similar transport features. Population centres included in the "metropolitan areas" are displayed on this figure.

Energy demand largely dependent on fossil fuel.
The final energy consumption in the passenger transport sector accounted for about 2,000 PJ in 2010 (Agency for Natural Resources and Energy, 2017). Most of this final energy consumption derives from petroleum products, although low-emission vehicles had started to penetrate the market, with 500,000 sales in 2010.

Historical trends over the period 1990-2013

Japan's population growth plateaued in 2010 and then started to decrease.

Total passenger transport demand and modal structure have more or less stabilized since the end of the 1990s (IEEJ, 2016).
Private road transport accounted for around two thirds of passenger transport between 1990 and 2013. In recent years, road transport demand has undergone a slight increase derived mainly from an increase in the use of private and commercial vehicles. Public transport is the second largest transport mode in Japan, with a share of about one third of passenger transport, reaching 34% in 2013. Trains account for a large amount of the public transport share, especially in urban areas where there is a high level of service. Finally, although aviation accounts for a small proportion of passenger transport in Japan, there has been a slight increase since the 1990s: from 4.0% in 1990, rising to about 5.8% in 2013.

Private car use is growing in both rural and urban areas, but the rate of growth has been moderate in recent years.
Since the 1990s the use of private cars slightly increased in metropolitan areas, however this growth had stopped by 2010 (MLIT, 2012). By contrast, the share of public transport in 2010 had increased from 2005. In rural areas, private car use continued to grow, exceeding 80% in 2010. However, the rate of increase was moderate compared to that of the 1990s (MLIT, 2012). The proportion of non-work-related transport (leisure, etc.) increased during the 1990s, representing about 30% of total weekday transport demand in 2010. By contrast, usage of transport for business, commuting and school fell during this period (MLIT, 2012).

Transport-related emissions and key features

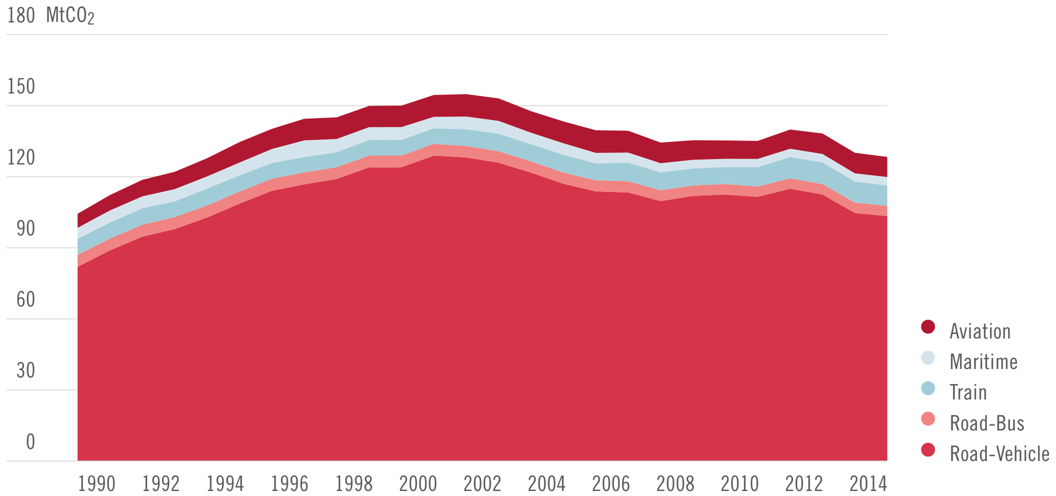
The passenger transport sector accounted for about 12% of the total energy-related CO_2 emissions in 2010, which represented about 137 $MtCO_2$.
As in many countries, about 90% of Japan's GHG emissions derive from energy-related CO_2 emissions. Emissions from the passenger transport sector increased by 50$MtCO_2$ over the period 1990-2002, reaching a peak of around 150$MtCO_2$ in 2002. From 2002 to 2014, passenger emissions slightly decreased by 20$MtCO_2$, reaching about 130$MtCO_2$ in 2014 (**Figure 2**).

80% of CO_2 emissions from passenger transport derive from private and commercial road transport.
Road transport is responsible for the largest proportion of transport-related emissions because the sector is mainly based on petroleum fuels. Aviation is the second largest emitter, accounting for about 20 $MtCO_2$, while trains are the third largest emitters, although in relative terms their impact is small due to a very high energy efficiency per passenger-km.

CO_2 emissions from passenger transport has decreased since the 2000s, while passenger transport demand has remained stable over this period.
The improvement of fuel economy and deployment of low-emission vehicles has contributed to a decoupling of transport demand and CO_2 emissions in this sector.

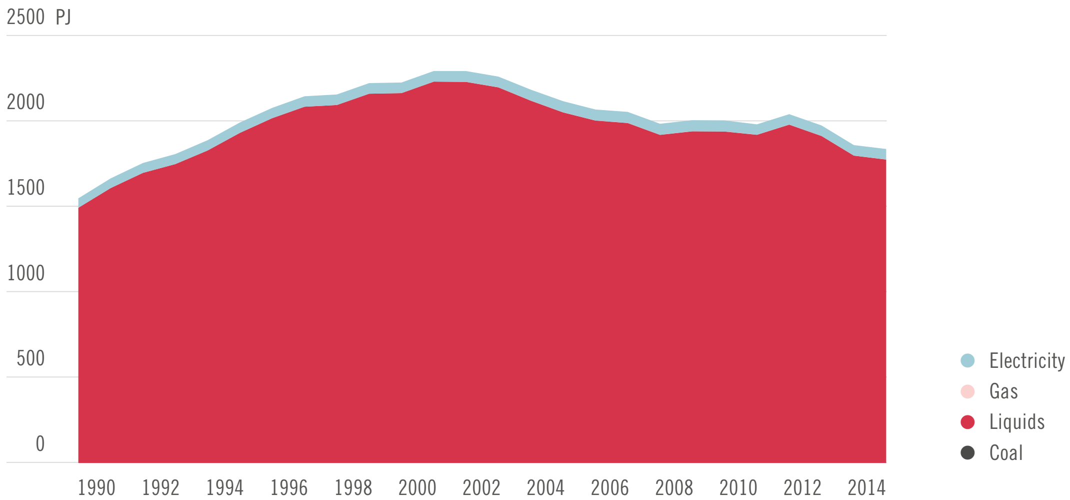
Energy demand has decreased since the 2000s due to fuel economy improvement. Final energy consumption in the passenger transport sector accounted for about 2,000 PJ in 2010, a figure that decreased by 2014 (**Figure 3**). Low-emission vehicle (LEV) sales almost tripled in the period from 2010 to 2016 (**Figure 4**), and although hybrid electric vehicles (HEVs) remain dominant in terms of vehicle sales, battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) have gradually emerged onto the market in recent years.

Figure 2. CO_2 emissions from passenger transport (direct + indirect)



Source: GIO (2017)

Figure 3. Final energy consumption in passenger transport sector



Source: Agency for Natural Resources and Energy (2017)

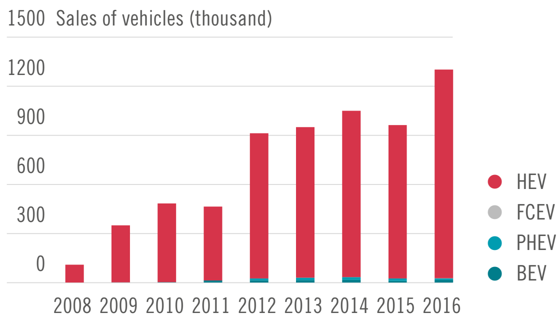
Note: Energy consumption is expressed based on gross calorific value.

Table 1. Historical passenger transport demand by mode

	1990	2000	2010
Total mobility (in Gpkm)	1,295	1,417	1,370
Road-Vehicle	57.1%	60.8%	59.3%
Road-Bus	8.5%	6.2%	6.3%
Train	29.9%	27.1%	28.8%
Maritime	0.5%	0.3%	0.2%
Aviation	4.0%	5.6%	5.4%
Total	100.0%	100.0%	100.0%

Source: IEEJ (2016)

Figure 4. Sales of low-emission vehicles (LEVs)



Source: JAMA (2017)

National policy framework on mobility and climate

Japan's Intended Nationally Determined Contribution (INDC), submitted on 17 July, 2015, is to achieve a reduction of greenhouse gas emissions in 2030 of 26%, compared to 2013 levels (Government of Japan, 2015). In the transport sector the INDC sets the target of reducing CO_2 emissions to 163 Mt-CO_2 by 2030, which is equivalent to a 32% reduction below the 2005 level (**Table 2**). As shown in **Table 3**, the INDC also sets out detailed mitigation measures by sector. In the transport sector, an emphasis is placed on the role of measures to reduce transport demand, such as traffic flow improvement and the promotion of public transport, as well as the improvement of fuel economy and deployment of low-emission vehicles (see **Table 2**).

In 2016, Japan adopted the Plan for Global Warming Countermeasures (MOE, 2016). This plan includes the target to increase the sales of next-generation vehicles – such as BEVs, PHEVs and fuel cell electric vehicles (FCEVs) – to 50-70% of new automobile sales by 2030, although it does not set out operational measures to reach this target. In addition, the plan sets a long-term mitigation goal of an 80% reduction of GHG emissions, however, the plan does not provide details on the target to reduce sectoral emissions by 2050.

In the private sector, Toyota has established a goal to reduce CO_2 emissions from new vehicles by 90% by 2050 relative to the 2010 level (Toyota, 2017). Similarly, Nissan has stated that CO_2 emissions from new vehicles must be reduced by 90% by 2050 compared to 2000, and has set a target to reduce CO_2 emissions through power source improvements and energy conversion (Nissan, 2017).

Table 2. Sectoral CO_2 emissions in the INDC

	Emissions in 2013 ($MtCO_2$)	Estimated emissions in 2030 ($MtCO_2$)	Reduction 2030 compared to 2013 (%)
Energy originated CO_2	1,235	927	-25%
Industry	429	401	-7%
Commercial and other	279	168	-40%
Residential	201	122	-39%
Transport	225	163	-28%
Energy conversion	101	73	-28%

Source: Government of Japan (2015)

Table 3. Mitigation measures in transport sector included in the INDC

◗ Improvement of fuel efficiency ◗ Promotion of next-generation automobiles ➔ Share of technologies (2012 → 2030) : HEV (3% → 29%), BEV, PHEV (0% → 16%), FCEV (0% → 1%), CDV (Clean Diesel) (0% → 4%)
◗ Other measures in transport sector ➔ Traffic flow improvement, promotion of public transport, modal shift to railway, etc.
◗ Utilization of the special zones system for structural reform for global warming measures
◗ Promotion of inter-ministry collaborative measures following roadmap of global warming measures, etc.

Source: Government of Japan (2015)

Storylines for the mobility determinants of two contrasting deep decarbonization pathways: Advanced Technological and Balanced

This section describes the social and technical transformations of the transport sector. These determinants influence the sector's emissions through dynamics of varying degrees of complexity, which is analysed in the next part of this paper. This section analyses the social and technical factors related to these determinants of mobility, namely: demographic and economic structure, human settlement and urban planning, lifestyles, infrastructure and mobility service deployment, vehicle technologies and energy generation, and distribution technologies.

We explored two Deep Decarbonization Pathways Projects (DDPP) scenarios to investigate the way in which different social and technical transformations can help achieve the required GHG emission reductions by 2050. An advanced technological (AdvancedTech) scenario focuses mainly on the different technical transformations in the transport and energy sector, but does not consider drastic social changes, such as urban structure, lifestyle or infrastructure. On the other side, the balanced scenario gives consideration to specific transformations of social factors, but also takes into account technical transformations in the transport and energy sector. This scenario aims to explore the potential of a drastic reduction in GHG emissions from an integrated and combined perspective of both technological innovation and changes in the Japanese mobility structure. It examines in detail the future transformation of constrained versus non-constrained mobility[1], in metropolitan and non-metropolitan areas to accurately describe the transformation of the demand and modal structure. To provide a balanced perspective, demographic changes, changes in population and the geographic distribution of activity (land use), social lifestyle changes, infrastructure development, advances in vehicle and energy sector technologies, etc., are taken into account, as well as the linkage and interaction between transport sector and other sectors.

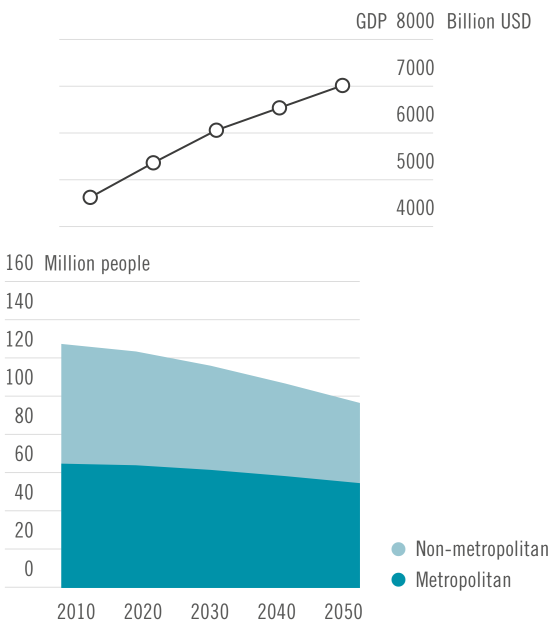
1 Definition: constrained activities are those where an individual has limited freedom to travel or not (work, school, shopping, administration…); non-constrained activities are those where an individual has more freedom on whether or not to travel (leisure activities).

Assumptions common to Advanced-Tech and Balanced scenarios

Demographic and economic changes

National statistics forecast that Japan's population is expected to decrease by around one quarter over the period 2010 – 2050, from 128 million to 97 million. In addition, the proportion of the population over 65 years old will increase from 23.0% in 2010 to 38.8% in 2050. This represents a fundamental transformation of the population structure over the coming decades. Over the same period we assumed that GDP will continue to grow at an average annual rate of 1.29%, while, accordingly, average household revenue will maintain stable growth (**Figure 5**).

Figure 5. Japan's population and GDP change (2010-2050)



Population centres and territorial distribution

Currently 51% of the population lives in the three main metropolitan regions (Tokyo, Nagoya, Osaka). The populations of these areas are predicted to grow, and more industries will be attracted in future. By 2050 it is estimated that about 57% of the population will live here (**Figure 1**). Due to increasing urban agglomeration and the concentration of economic development in these three metropolitan regions, it is likely that the metropolitan areas will be inhabitant by a richer segment of the population. Although poorer people will also be attracted to metropolitan areas in search of job opportunities and urban facilities, such as shared apartments and social housing. However, the total population of metropolitan areas will decrease from 65 million to 55 million between 2010 and 2050. As a result, the majority of public services will become concentrated in the more densely populated areas, and may disappear from some non-metropolitan areas, which will increase the travel distances for non-leisure related transport (work, school, administration…) in these areas.

Lifestyles and mobility services

Richer people tend to prefer private, rapid, and comfortable modes of transport, a tendency that will continue in future. To encourage the use of public transportation, the planning, management and operation of public transportation systems are of great importance. Cars will remain dominant and will continue to be a symbol of freedom, but the development of high quality public transport could partially counter this trend in metropolitan areas. There may be a slight increase in the time available for leisure activities which, combined with an increase in disposable income, could lead to a greater demand for mobility for recreational purposes.

Infrastructures and urban planning

Japan's road network is currently the country's most important transport infrastructure. The population decline in Japan is likely to partially mitigate congestion problems in the most densely populated areas.

Vehicle transformations

The electrification of the vehicle fleet is one of the major technological trends that is clearly evident in Japan. For our analysis, we assume that more than 90% of light duty vehicles (LDVs) could be electrified, and also buses and the majority of trains.

Energy system transformations

The electrification of the vehicle fleet through the introduction of PHEVs, BEVs, etc., will contribute to a reduction of the consumption of liquid fossil fuel, but a dramatic increase in electricity consumption. Gas will be more widely used in the major transportation sectors. The proportion of biofuel will increase and gradually replace liquid fossil fuel. The scenarios assume that the carbon content of transport fuels will be reduced because an increased amount of fuel will be able to be supplied by renewable and sustainable sources. A large proportion of electricity is generated by renewables and CCS-equipped plants. Electro-mobility will increase the demand placed on the electricity distribution network, and also the demand for electric vehicle charging stations. The gas distribution network will need a long-term investment in pipelines.

The AdvancedTech DDPP transport scenario: technological changes alone to decarbonize

Socio-economic transformations

In the AdvancedTech scenario, significant economic development produces an increase in the population's capacity for mobility, which counteracts the effect of an ageing population on mobility. In addition, this scenario does not take into account any specific assumptions on the transformation of the organization of metropolitan areas and considers no change of individual mobility preferences and societal trends. This scenario considers therefore a continuing development of private mobility with an increase in the motorization rate of households and a limited uptake of autonomous vehicles.

Technological transformation of the transport sector

As a transition away from private vehicles towards public transport is not taken into account in this scenario, there is only a very limited need for new transport infrastructure. Thus, this scenario does not consider an investment break towards other modal infrastructure.

Regarding vehicle transformations, AdvancedTech assumes that BEVs will be economically competitive by 2050 given a sufficient carbon price and therefore over 90% of LDVs will be electrified by 2050 in this scenario.

Although FCEVs will be available and economically competitive by 2050 in the passenger transport sector, most low-carbon hydrogen is likely to be used in freight transport because alternative low-carbon options for heavy trucks are limited. The scenario includes a drastic reduction in fuel demand for buses by 2050, due mainly to improved fuel economy. However, the spread of full-electric buses in this sector is very limited. Finally, the scenario assumes that most of the country's railways will be electrified by 2050 (over 90%) due to the decarbonization of electricity.

Technological transformation of the energy sector

The electrification of the vehicle fleet through the introduction of PHEVs and BEVs will contribute to a reduction of the consumption of liquid fossil fuel, but a dramatic increase in electricity consumption. As most electricity is generated by low-carbon sources, such as renewables, nuclear and fossil fuel with CCS, the carbon intensity of electricity will fall to nearly zero by 2050. The strong decarbonization in the power generation sector will be realized through a massive deployment of CCS and renewable energies. The share of renewable energies and CCS-equipped plants in the scenario reaches high proportions of the total electricity generation. Furthermore, the scenario assumes that the carbon content of transport fuels will be reduced because most fuels will be derived from low carbon electricity and biofuel.

Electro-mobility will increase the demand placed on the electricity distribution network and also the demand for electric vehicle charging stations. As the proportion of BEVs begins to increase among LDVs, vehicle-to-grid (V2G) can contribute to the greater integration of variable renewable energy (VRE) into the electricity grid. It is interesting to note that an increase in BEVs and the use of smart charging technology should provide grid reliability benefits that help mitigate problems associated with the curtailment of electricity generated from variable renewable energies, such as solar PV and wind power. This would make BEVs economically attractive, because BEV owners will be able to purchase cheaper electricity under a dynamic pricing system.

Regarding the future of refuelling stations, public petrol and diesel fuel stations will decline as the numbers of internal combustion engine cars on the road gradually decrease. The efficiency and safety of charging stations will be further improved, encouraging more people to use electric vehicles.

Balanced DDPP transport scenario: behavioural changes contribute to the decarbonization

Demographic and economic changes

Future transport demand will be influenced by Japan's aging society. The average individual level of mobility among the elderly proportion of the population is lower than the average of the population as a whole, a trend that we consider will continue.

Lifestyles and mobility services

The Balanced scenario includes two important socio-cultural transformations: an increase in the use of mobile communications and car sharing. Mobile communications, which enable teleworking, online shopping, teleconferencing, etc., will be strongly encouraged to reduce the demand for commuting and daily trips. For example, teleworking can cut out one day of commuting per week, while teleshopping can result in a 10-20% reduction of shopping trips.

Carpooling and car sharing will also be promoted to reduce the number of motorized trips by increasing car occupancy rates. In non-metropolitan areas carpooling services have a major market potential because small and low-density communities have inadequate public transport networks. The promotion of carpooling and car sharing services should therefore be emphasized in non-metropolitan areas. The scenario assumes that the car load factor will increase from 1.54 in 2010, to 2 in 2050.

Infrastructures and urban planning

Japan's metropolitan areas will be transformed in future, their structure changing to support the development of areas with more diversified activities, concentrated within the same perimeter. The population decline in Japan must be taken into account when re-thinking the compact cities of the future. This transformation of space and land use will reduce the distance travelled for work-related trips in metropolitan areas by 10-20%. Moreover, it will be possible for metropolitan areas to reallocate a proportion of road space to support the development of public transport and soft modes of transport. The scenario anticipates that urban planners will design pedestrian-friendly streets: with larger areas for pedestrian zones, cycling lanes, and with smaller city blocks. Thus, encouraging people to use non-motorized transport (NMT) and buses as alternatives to short distance car journeys. In metropolitan areas, road speed limits will be restricted for reasons of road traffic safety and pollution, while the speeds of public transit options can be increased to provide a better service. The public transport infrastructure will play an increasingly important role in future and there will be an increase in the development of such infrastructure. There is also a need for more public transportation, such as trains, in non-metropolitan areas to allow a reasonable modal shift away from private cars for work-related activities.

Regarding the infrastructure for long distance journeys, such as airports and high-speed railways, the Balanced scenario assumes that no new airports will be constructed, but that the government will continue to build high-speed railways. In total, we assume that a reduction of around 10-20% in domestic long-distance air travel can be achieved through a modal shift from air to rail, leading to a reduction in the use of jet fuel.

Vehicle transformations

Smaller and lighter cars will be encouraged to reduce energy consumption and mitigate congestion. By 2050, more than one quarter of the vehicles on the road will be autonomous, which can, to some extent, also help mitigate traffic congestion and reduce energy consumption. The cost of public transport will be lower than that of private transport.

Energy system transformations

Regarding the fuel generation, the price of electricity will decrease, encouraging the use of electric vehicles, while the imposition of a carbon tax will increase the price of liquid fossil fuel. In addition, although aviation will continue to rely on jet fuel, the scenario assumes its gradual replacement with biofuel.

In addition, the scenario assumes that more filling stations for biogas and liquid biofuels will be built to meet the rising demand, while the number of conventional filling stations will fall due to the decline in the number of internal combustion engine cars on the road. Remaining liquid fossil fuel pumps could be adapted to integrate liquid biofuels. The efficiency and safety of charging stations will be further improved to encourage more people to use electric vehicles.

Table 4. Summary of AdvancedTech and Balanced scenarios main assumptions

Determinants	AdvancedTech scenario	Balanced scenario
Demographic and economic changes	Population decline; aging society Steady economic growth	- same -
Population centres and territorial distribution	Concentrated; agglomerated in the main metropolitan areas	- same -
Lifestyles and mobility services	No change of current trend	Increase of teleworking and online shopping; Development of car sharing and carpooling
Infrastructures and urban planning	No change of current trend based on car oriented design	Mass transit-oriented development; pedestrian-friendly streets; High-speed railway construction; Speed regulation for private modes in metropolitan areas; Lower public transport cost High-density cities, but mixed, and diversified land use
Vehicle transformations	Electrification of mobility; Energy efficiency improvement;	- same -
Energy system transformations	More electricity generated from renewable sources and CCS-equipped plants; More EV charging stations	- same -

Results – Evolution of emission drivers and related transformations for AdvancedTech and Balanced scenarios

This section highlights some key quantitative indicators to compare changes in mobility-related emissions according to the two scenarios. The changes of these quantitative indicators result from the combined effects of the social and technical transformations of the main factors described in the previous section.

The starting point and calibration of our scenarios at the year 2010 is based on two main sources: the previous AIM model and The Nationwide Person Trip Survey (2010).

AdvancedTech scenario: energy efficiency and fuel decarbonization

Summary

Average individual emissions per km decrease by 68% between 2010 and 2050. In addition, although the average annual distance travelled per capita increases by 25% over this period due to high economic growth, the average individual energy consumption per km and the average carbon emissions resulting from 1J of energy consumption fall by 44% and 43%, respectively. Improvement of energy efficiency and emissions intensity is mainly derived from the electrification of vehicles, as well as the deployment of energy-efficient vehicles such as HEVs. Oil consumption is shown to decrease by 68% between 2010 and 2050, while a steep increase in electricity demand, from 19.5 to 108.7 TWh, is observed. This trend contributes to drastic emissions reductions in this scenario, independently of the effects of other low-carbon carriers, such as biofuel and hydrogen. The scenario forecasts almost no change in modal structure, apart from a 28% increase in the proportion of air transport out of total transport by 2050.

Technological options would be able to contribute significantly to the reduction of emissions from passenger transport, however, without measures to reduce

Figure 6. Average energy intensity and average carbon emissions intensity

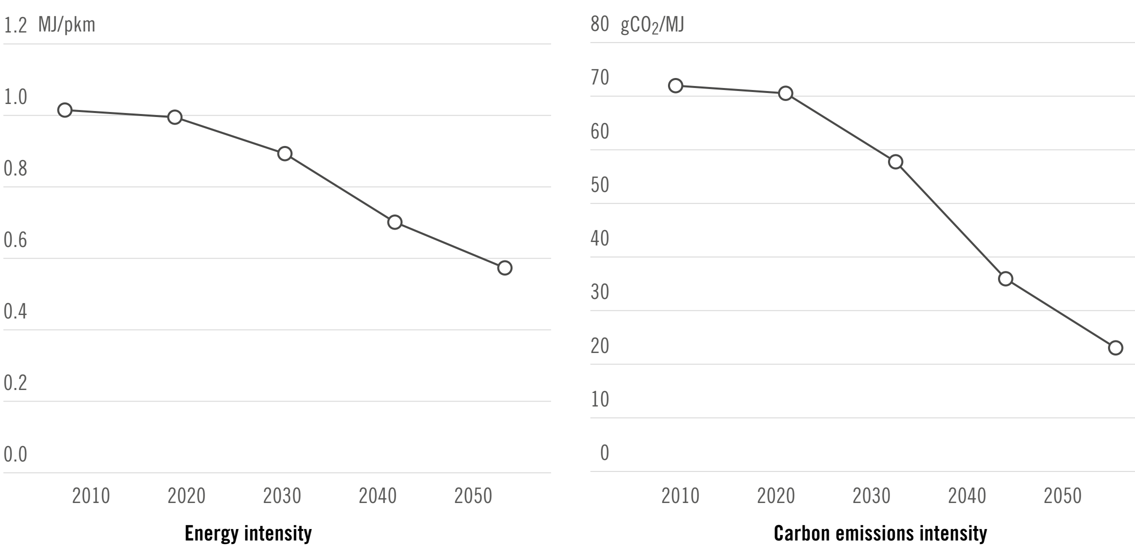


Figure 7. CO_2 emissions from passenger transport

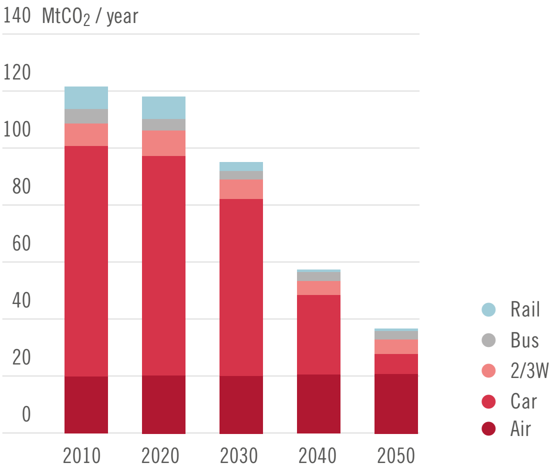


Figure 8. Individual mobility, constrained/non-constrained related for metropolitan and non-metropolitan areas

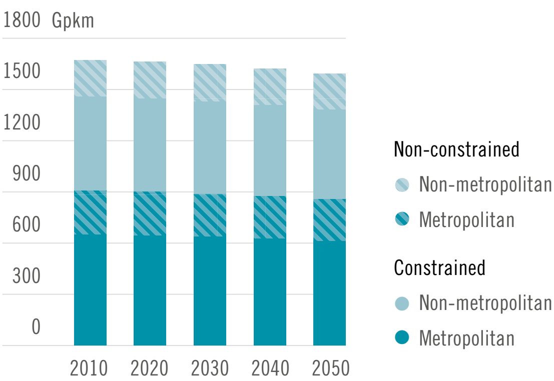
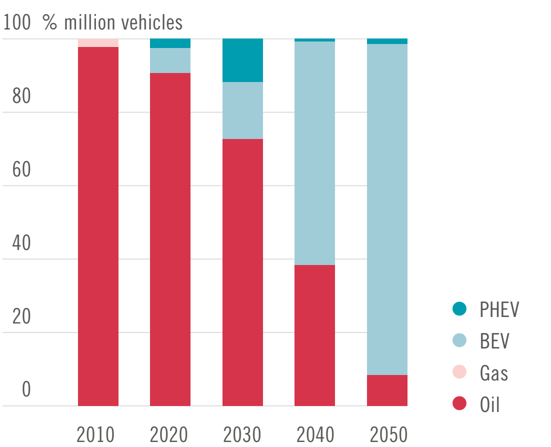


Figure 9. Vehicle fleet according to technology



"Oil" : thermal motorization fueled by liquids (gasoline, diesel, liquid biofuels)
"Gas" : thermal motorization fueled by gas (natural gas, biogas)

transport demand, huge efforts would be required to transform transport systems, not only in terms of the diffusion of electric vehicles, but also regarding investments in associated infrastructure, such as increasing the number of charging stations.

Mobility demand and individual demand

Under this scenario the individual daily average distance travelled in 2050 increases by 25% compared with the 2010 level, despite Japan's aging society. This is due to a rise in disposable income, derived from the growing GDP, an increasing proportion of which is spent on travel. However, in metropolitan areas, the average daily distance travelled shows a slight increase by 2050, and a decline in the average daily travelling time of 36%.
Although there is an increase in the average daily distance travelled, the total transport demand decreases slightly towards 2050 in both metropolitan and non-metropolitan areas, due to population decline. Consequently, metropolitan areas represent more than half of the transport demand by 2050.

Private car mobility – electrification

Although car mobility demand still represents about 91% of the 2010 level in 2050, CO_2 emissions from metropolitan areas decreases by about 65% during this period due to improvements in the emission intensities of vehicles. In particular, the electrification of car mobility is key, as the carbon content of electricity falls to 13 g-CO_2/kWh by 2050, equivalent to a 97% reduction of the 2010 level, due to the deployment of low-carbon electricity, such as renewables, nuclear and CCS.
The average number of vehicles per 1,000 people increases by 22% from 2010 to 2050. Moreover, by 2050 the total vehicle fleet includes 49.3 million low carbon vehicles, which includes a large-scale deployment of electric vehicles.
In terms of aviation, thermal efficiency improves by about 14% between 2010 and 2050, which contributes to an emissions reduction without involving a fuel switch to low-carbon resources.

Infrastructure transformations: mode, energy generation and distribution

Due to electrification and improved fuel economy, the scenario forecasts a decrease of 87% in the number of petrol refuelling stations between 2010 and 2050.

Figure 10. Energy demand in passenger transport sector

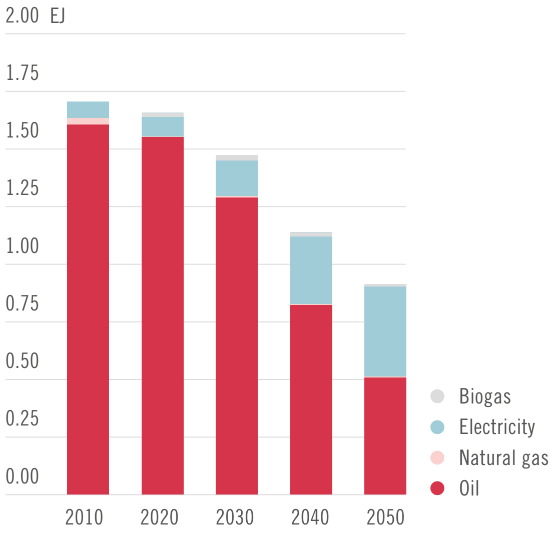
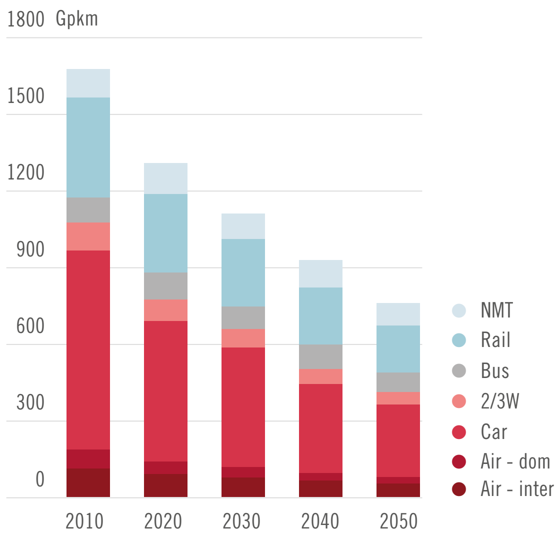


Figure 11. Passenger transport demand

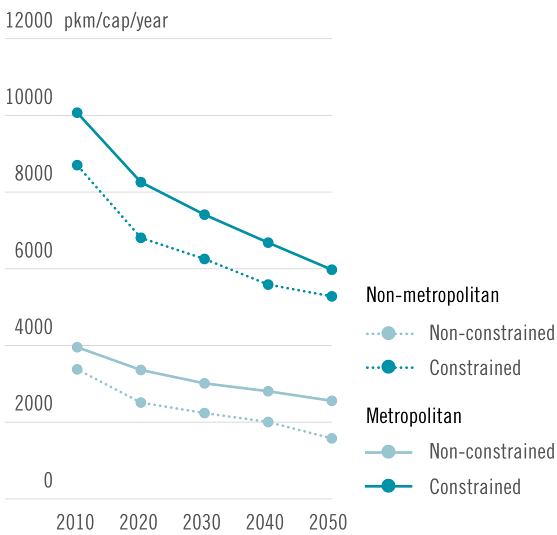


By contrast, the number of charging stations will need to be quadrupled over this period as a result of the promotion of electric vehicles. Although investment will be necessary to build a sufficient number of charging stations, an increase in BEVs would help reduce curtailment problems associated with the variability of renewable energy such as solar PV and wind power. The scenario forecasts a large increase in electricity demand from the transport sector, but its impact on the total electricity demand in Japan is limited, because the buildings and industrial sector consume much more electricity, as shown in our previous analysis (DDPP1).

Balanced Scenario: demand reduction and modal shift

The total passenger transport demand will decrease rapidly from 1,676 Gpkm in 2010 to 759 Gpkm in 2050, at an average annual rate of 1.37% due to a combination of fundamental transformations: population decline, aging of population, car ownership reduction, increase of teleworking and online shopping, and finally, structural land use and urban planning policies (**Figure 11**).
Although the car is still the dominant means of passenger transport, it has the most significant reduction. The average yearly distance travelled per capita decreases from 13,088 passenger-km per capita in 2010 to 7,821 passenger-km per capita in 2050. As shown in **Figure 12**, in metropolitan areas, the average yearly distance travelled per capita for constrained mobility will decrease from 10,080 to 5,984 pkm/cap, while the average yearly distance travelled per capita for non-constrained mobility will fall from 3,962 to 2,563 pkm/cap. Although both the average daily distance travelled in metropolitan and non-metropolitan areas display similar declining trends, individual mobility

Figure 12. Individual mobility, constrained/non-constrained related for metropolitan and non-metropolitan areas



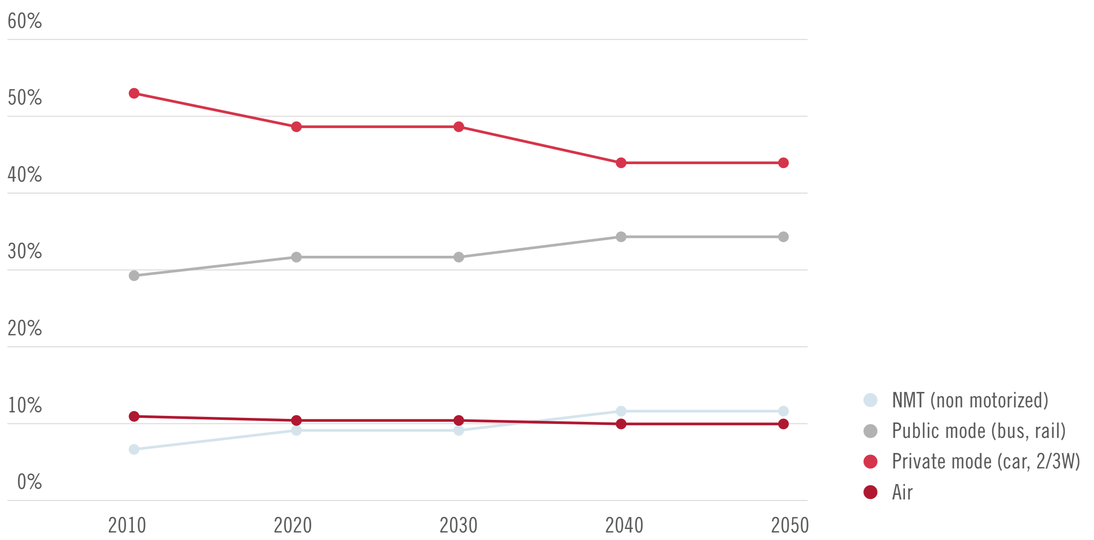
in metropolitan areas remains higher than that of non-metropolitan areas, which suggests that economic prosperity in metropolitan areas may generate more business activities and higher income levels, which could increase the demand for transport.

This scenario forecasts a steady decline in the total transport demand due to the continuing decrease in Japan's population. Individual mobility also shows a significant reduction compared with the 2010 level, despite the expected higher disposable income of households due to GDP growth. The main reason for this phenomenon is Japan's "super-aging" society. The individual mobility of elderly people is lower than that of young people, which leads to a reduction of average individual mobility. Another reason is urban planning and land use policies. More concentrated and agglomerated systems of urban spatial organization and compact land use patterns can effectively reduce the daily distance travelled. The compact city concept puts the emphasis on grouping urban activities within close proximity to ensure better access to services and facilities via public transport, walking, and cycling. Long-distance travel generated by urban sprawl is avoided due to high-density mixed-use, and urban intensification. Additionally, lifestyle changes such as teleworking and online shopping result in a reduction of commuting and shopping trips.

There is a shift away from private modes of transport (cars, two and three wheelers) towards public transport modes (buses, trains) and non-motorized travel modes (walking, cycling). The scenario forecasts a decrease in the modal share of private modes of transport from 53% in 2010 to 44% in 2050, while public modes of transport and NMT will increase from 29% to 34% and 7% to 12%, respectively. The proportion of air travel will decrease from 11% to 10% during 2010 to 2050, because more travellers opt for high-speed trains rather than planes for domestic travel (**Figure 13**).

The modal shift demonstrates that the preference for bus, rail and non-motorized travel modes will be facilitated through spatial transformations of urban and land use patterns, such as the size of urban areas, density, plot ratio, mixed land use, close grouping of facilities, regional accessibility, road and path connectivity, roadway design, and facilities for cycling and walking. More compact, mixed, multi-modal, transit-oriented, pedestrian-friendly, walkable city planning is a promising solution to help decrease the usage of private modes of transport, while promoting the public transport system. New urban spaces allocated to public roads, parking, public transport systems such as bus rapid transit (BRT) and pedestrian systems are needed to support transit-oriented and pedestrian-friendly designs in metropolitan areas. As urban areas and structures become more concentrated, compact, and pedestrian-friendly, travellers will be motivated to use public transport, walking, and cycling for commuting, shopping, and other purposes.

Figure 13. Modal split



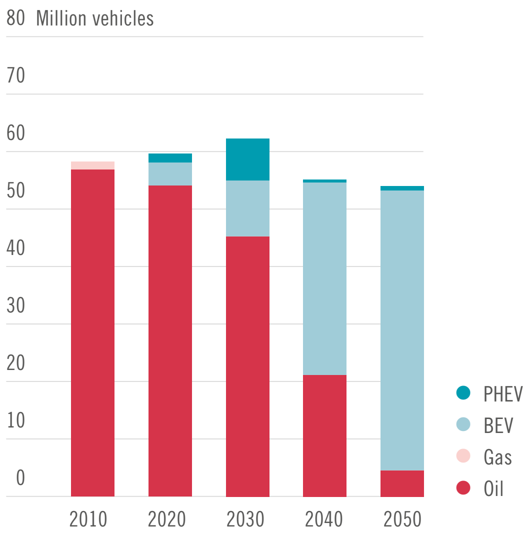
The scenario forecasts a decrease of the total car fleet from 58.1 million to 53.9 million from 2010 to 2050 (**Figure 14**). This includes a dramatic decline in the numbers of liquid fossil fuel vehicles, from 57 million to 5 million, and a rapid increase in low carbon vehicles, which reaches almost 100% of the car fleet because the balanced scenario assumes that PHEVs and BEVs will be strongly promoted in future given their environmentally friendly credentials. The average individual energy consumption per km decreases from 1 to 0.4 MJ/pkm by 57% under this scenario. Due to the electrification of road transportation, the most striking transformation in the energy supply is the replacement of oil with electricity. Oil consumption is forecast to decrease from 1.61 EJ in 2010 to 0.18 EJ in 2050, while electricity increases sharply from 0.07 to 0.14 EJ during 2010 to 2050 (**Figure 15**). The reduction of energy consumption and the shift away from liquid fossil fuel derives from the decrease in individual mobility, the modal shift, an increasing occupancy rate, and technological improvement in energy efficiency.

The switch from fossil fuels to electricity results in a declining number of petrol fuel stations, whereas the widespread use of electric-powered vehicles will lead to a rise in the number of charging stations. Japan is improving its electric charging infrastructure to encourage the use of electric vehicles, and the development of the charging infrastructure would be an important element of continued market growth.

The Balanced scenario depicts a decarbonization strategy which demonstrates the potential for GHG emissions reduction. As shown in **Figure 16**, CO_2 emissions will be reduced by 89% from 120.7 Mt to 13.4 Mt during 2010 to 2050. Average individual emissions per km trip decrease from 72.0 gCO_2/pkm in 2010 to 17.6 gCO_2/pkm in 2050, with a decreasing rate of 76%. Car mobility is the biggest contributor to emissions reduction, which will decline from 80.6 Mt to 1.8 Mt. Aviation will replace the car as the largest contributor to emissions by 2050.

Such a significant reduction of carbon emissions stems from the rapid decline in car mobility and the electrification of road transportation. Car mobility demand decreases by 72% from 507 to 143 Gvkm over the coming four decades due to the reduction in transport demand and an increasing car occupancy rate. In addition, due to renewable energies and the deployment of CCS-equipped plants in the power generation sector, the carbon content of electricity will decline by 97% from 394.5 to 13.4 gCO_2/pkm, which will contribute to

Figure 14. Car fleet



"Oil" : thermal motorization fueled by liquids (gasoline, diesel, liquid biofuels)
"Gas" : thermal motorization fueled by gas (natural gas, biogas)

Figure 15. Energy consumption

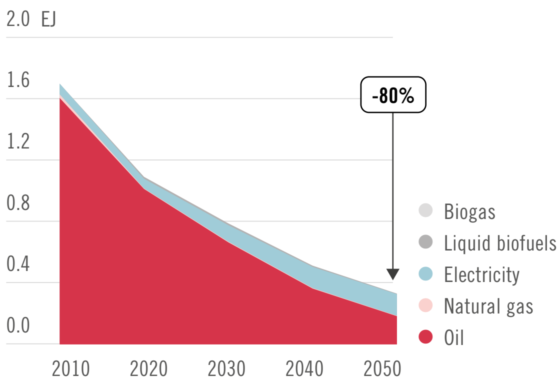
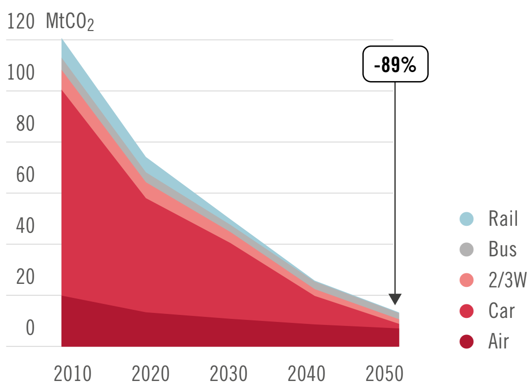


Figure 16. Emissions



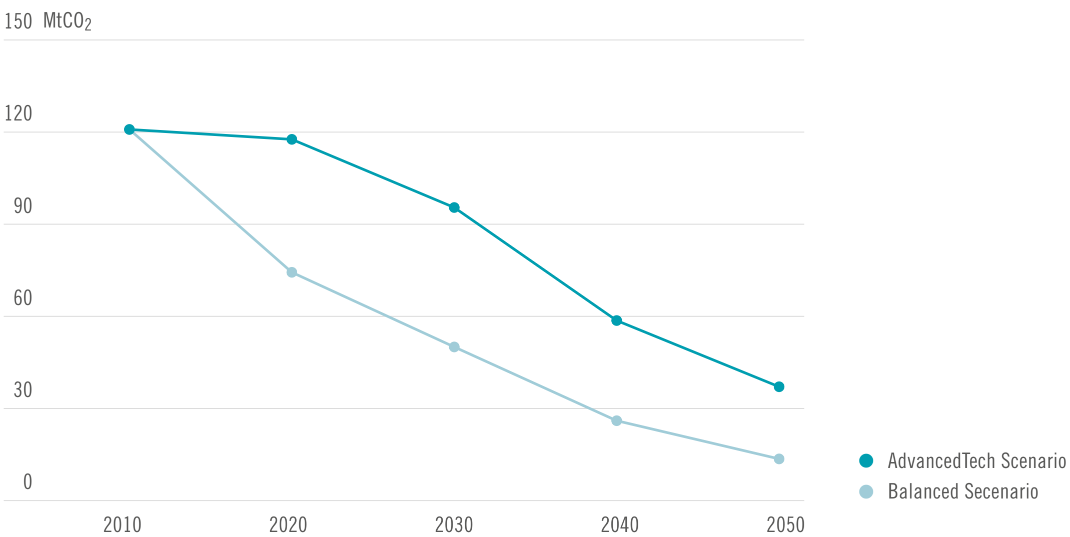
a decline in GHG emissions because electric vehicles will have a large market share.

Comparative analysis

The emission trajectory of the Balanced scenario shows lower emission values than those of the AdvancedTech scenario (**Figure 17**). Compared with the annual decline in the rate of emissions (-1.74%) in the AdvancedTech scenario, the Balanced scenario has a more significant annual reduction rate (-2.22%). It is notable that the consideration of social transformations is helpful for the further reduction of emissions on the basis of the mitigation potential of technological transformations. Social and behavioural changes in demography, urban structure, land use, lifestyle, etc., should receive more attention because they can effectively contribute to the deep carbonization of the transport sector.

In both scenarios, low carbon fuels play an important role in achieving low-carbon transport, particularly electricity, because a massive decarbonization of electricity generation is forecast due to the large-scale deployment of low-carbon energy. For all vehicles, improvements in fuel economy contribute to CO_2 emissions reduction. However, reducing emissions from aviation is a challenge and the proportion of CO_2 emissions derived from air transport becomes considerable by 2050.

Figure 17. Emission trajectories of the AdvancedTech and Balanced scenarios



Policy implications

Discussion on adapted policy measures

According to Intended Nationally Determined Contributions (INDCs), CO_2 emissions from the passenger transport sector should be reduced to 101 Mt by 2030, assuming the share of passenger transport is the same in 2030. The Plan for Global Warming Countermeasures (MOE,2016) also sets a long-term mitigation target to reduce GHG emissions by 80%. It will be incredibly difficult to achieve these stringent mitigation goals without the implementation of positive policies and measures. The INDCs and the Plan for Global Warming Countermeasures propose low-carbon policies such as the promotion of public, transport, improvement in fuel efficiency, the modal shift to railways, the promotion of next-generation automobiles, etc., which are supposed to contribute to the achievement of GHG emissions reduction. The results of the AdvancedTech and Balanced scenarios prove that technological innovation alone will not be sufficient, and that the transformation of societies, urban configurations, and human behaviours will be needed to achieve transport-related GHG emissions reduction targets. Thus, it is possible to draw up a roadmap to provide a comprehensive and multidimensional policy tool for long-term decision-making in transport decarbonization.

Development and promotion of low-carbon transport technologies

To tackle the issues associated with the decarbonization of the transport sector, environmentally-friendly vehicle technologies such as electric or hybrid cars will play the most important role. For the near term, a reduction of liquid fossil fuel can be achieved directly as a result of the deployment of hybrid vehicles, since hybrid vehicles may become a significant fraction of new vehicle sales. In the longer term, BEVs should be strongly promoted to achieve the goal of deep decarbonization. For a significant reduction in GHG emissions from the transport sector, BEVs appear to be the best option to achieve the ultimate goal of zero emissions.

Since the corresponding reduction in GHG emissions entirely depends on the emission intensity of the electricity used to charge BEVs, newly built power stations should be CCS-equipped and use renewable energies. In addition, the successful promotion of electric vehicles is likely to be essential to achieve a widespread commercialization of electric-powered vehicles and the construction of publicly accessible charging infrastructure.

Urban planning and transit-oriented development strategies for decarbonized transport

As a public policy, urban planning should aim to design the urban structure and land use layout for the purpose of optimizing the effectiveness of a community's land use and infrastructure. The decarbonization of the transport sector requires new and innovative urban planning strategies. Japan's aging population, which is rapidly becoming more concentrated into metropolitan areas, presents both a challenge and an opportunity for future urban development and restructuring. Compactness and mixed land use should be the core ideologies of urban planning. Compactness, by which we mean high-density, mixed and intensified land use, is necessary to design an effective low-carbon transport system because urban activities can be relocated to bring them closer together, reducing the need for long-distance travel and usage of private modes of transport. The essence of the compact city is that a centralized urban area should promote diverse and intensified land use and improve the efficiency by reuse of current land resources, land replotting, and urban renewal, instead of disordered urban sprawl and urban land expansion. Importantly, urban policy-making should aim to avoid the conversion of land use in non-metropolitan areas, and to limit the migration of the population from cities to low density residential developments on rural land.

To ensure that public transport is a priority and to build a transit-oriented society, it is necessary to establish a public transit system with improved accessibility, security and comfort to encourage a preference for public transportation. Specifically, the density of the transit network, station coverage, and the frequency of departures must all be increased to develop an attractive physical environment and level of service. In addition to transit-oriented development, a considerable focus on non-motorized transport is required. The key point here is the design of a barrier-free pedestrian system to ensure that metropolitan households can move from residential zones to other places of activity via a pedestrian system that serves as a slow traffic corridor. Since a slower pace of transport activities is becoming common as increasing number of senior citizens, non-motorized slow transport system would be the central topic in transport policy-making with the coming of greying society in Japan. A slow transport system must include a pedestrian-friendly street design, due to the fact that long-distance travel is impracticable for walking or cycling in case that land use layout is dispersed and scattered.

Lifestyle changes and emissions reductions in the transport sector

Lifestyle changes will have a significant impact on the reduction of traffic congestion and commuter overcrowding, which will contribute to GHG emissions reduction in the transport sector. In metropolitan areas, particularly in central business districts, there will be more pressure on road transportation, despite the declining population, due to the increasing concentration and agglomeration of urban centres. The government will need to launch a scheme to encourage companies to break with tradition and allow employees to work from home in an effort to reduce traffic congestion and commuter numbers. Although the more progressive companies have already introduced teleworking days or flexible working, the government still needs to support companies to change and to understand the potential also in terms of worker productivity. For example, the government could develop an economic incentive system to encourage companies to meet specific targets in terms of their numbers of teleworking employees. Under such a policy, more companies would recognize the benefits of allowing employees to work from home.

First priorities by 2025

There are many policy initiatives and measures that can be considered to achieve the goal of deep decarbonization in the transport sector. However, policy uncertainty may lead to the risk that the decarbonization pathway fails and the targets are not achieved as planned. Therefore, it is necessary to implement all policy initiatives and to consider which are the first priorities for the near future to ensure the achievement of the goal, and to avoid any lock-in effects that might influence deep decarbonization pathways. The main priorities by 2025 are therefore set out below for the two scenarios, which should enable the expected targets to be attained.

Vehicle efficiency improvement

Technological transformations, such a deep electrification in the transport sector, are long-term in nature and will require profound changes to energy, infrastructure, and the national macroeconomic system. Since the mass adoption of electric vehicles cannot be achieved in the short-term, immediate action on efficiency improvements in conventional internal combustion engine-driven vehicles is required. Moreover, improvement in aircraft fuel efficiency deserves more attention, since aviation will consume the largest proportion of liquid fossil fuel following the electrification of road transportation. The energy efficiency of air travel and the potential for further innovation in energy-saving aircraft technologies need to be emphasized over the coming decade.

Balance between technological and social transformation

Social transformations, not only technological improvements, are a vital aspect of a decarbonized transport system. Social transformations such as lifestyle changes and low-carbon urban reorganization can be effective within a relatively short period. A balanced approach involving technological and social transformations can mitigate the risk that an approach based solely on technological innovation might fail in terms off developing an energy efficient and decarbonized transport system. In the near term, activities such as teleworking and online shopping should be strongly promoted. Investment in public transport and pedestrian-friendly infrastructure, such as dedicated routes for buses and trains, high-speed railways like maglev trains, etc., could help persuade more travellers to move away from carbon-intensive modes of transport. If lifestyle changes and infrastructure investment are focused on low-carbon and transit-oriented urban planning, it should be possible in the short term to achieve a rapid shift onto a pathway towards the deep decarbonization of transport.

Standardized DDPP graphics for Japan scenarios

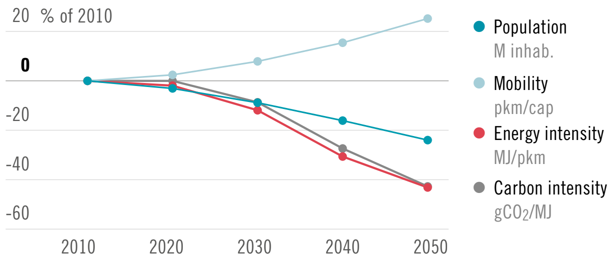
AdvancedTech Scenario

Balanced Scenario

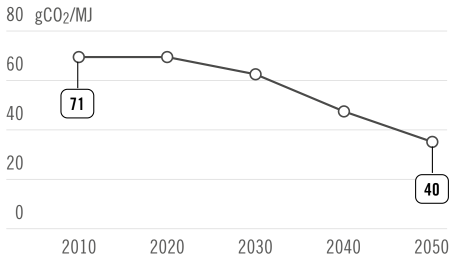
JAPAN - AdvancedTech (ADV) Scenario

A1. National energy consumption and related emissions

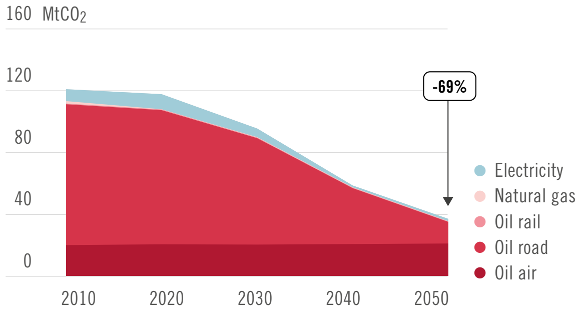
1.a Emission drivers



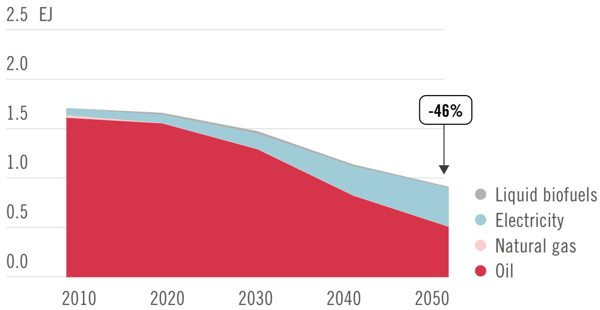
1.c Carbon content of energy



1.b CO_2 emissions



1.d Final energy consumption



A2. The pillars of decarbonization

Pillar 1
Energy efficiency

Individual Mobility: 13 → 16 (+ 25%), 000s pkm/cap

Energy intensity: 1.0 → 0.6 (- 44%), MJ/pkm

2010 · 2050

Pillar 2
Decarbonization of electricity and fuels

Carbon content of electricity: 395 → 13 (- 97%), gCO_2/kWh

Biofuel in blended fuels *: 0 → 2 (+ 2 pt), % blended fuels

** Liquid fuels and pipe gas*

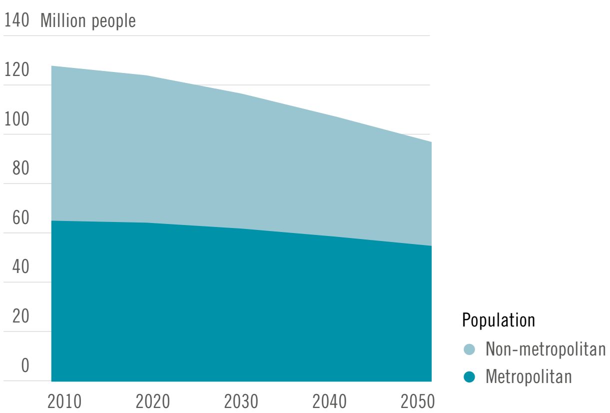
Pillar 3
Shifting to low carbon fuels

Non fossil fuel energy **: 4 → 43 (+ 39 pt), % of total energy

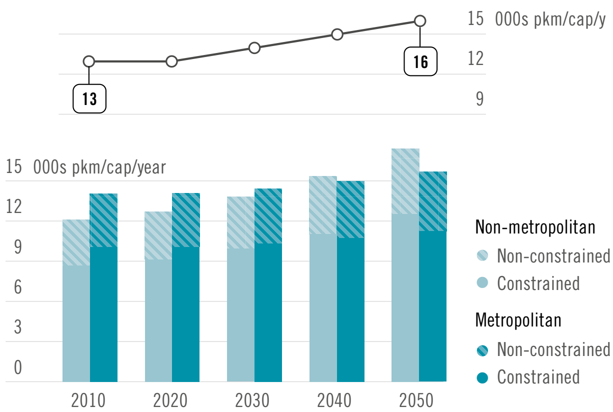
*** Integrating electricity, liquid and gaseous biofuels, hydrogen*

A3. Population and mobility

3.a Metropolitan and non-metropolitan population

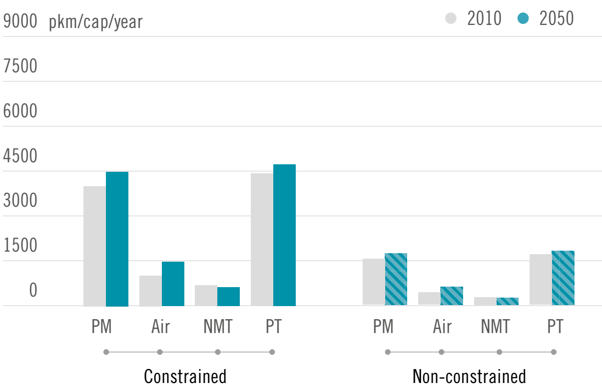


3.b Constrained and non-constrained mobility

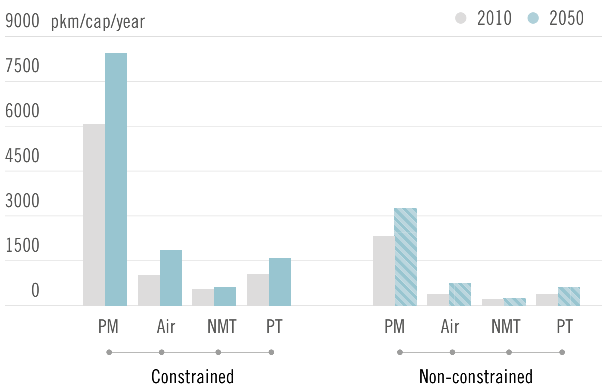


A4. Modal structure

4.a Metropolitan



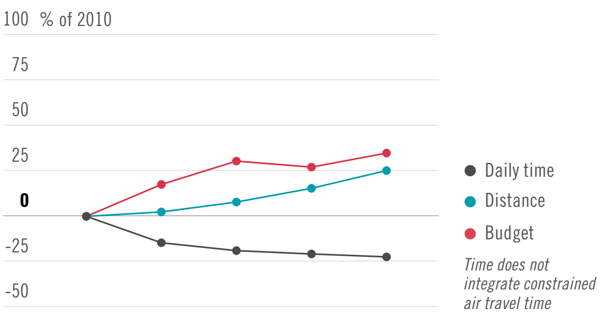
4.b Non-metropolitan



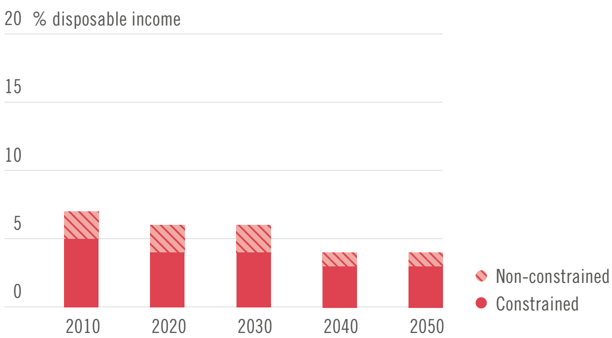
PM = Private Mobility (car and 2W), NMT = Non-motorized transport (walking, biking…), PT = Public transport (bus and rail)

A5. Mobility indicators

5.a Indicators for constrained mobility

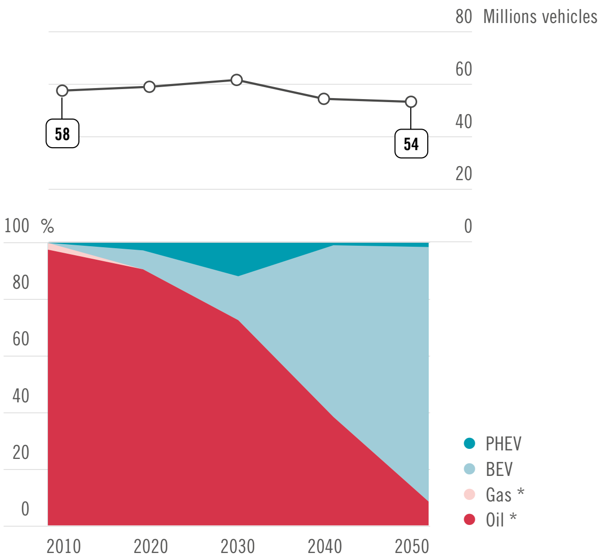


5.b Transport budget

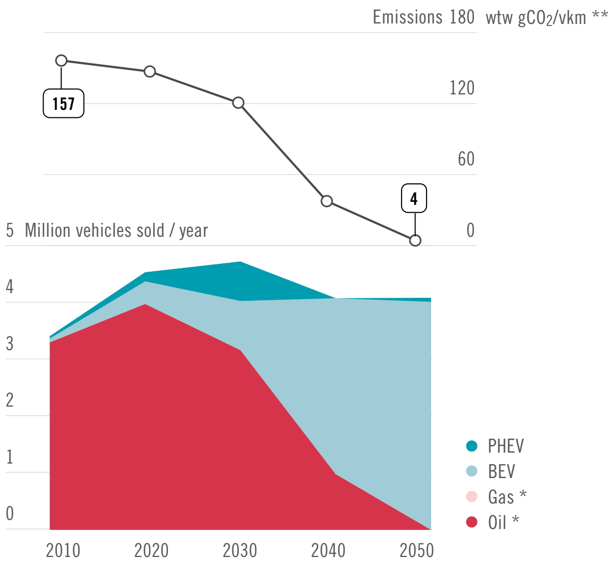


A6. Car mobility

6.a Car stock



6.b Car sales and related emissions



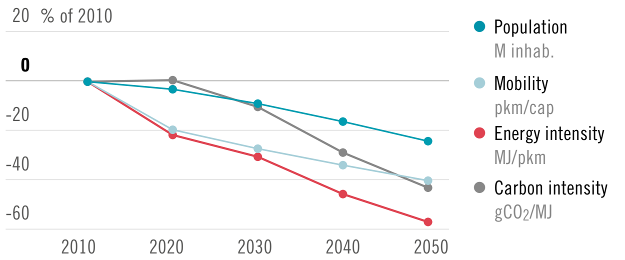
* "Oil" means thermal motorization fueled by liquids (gasoline, diesel, liquid biofuels); "Gas" means thermal motorization fueled by gas (natural gas, biogas)

** Emissions of average car sales is expressed in "well-to-wheel" gCO_2 per vehicle-km travelled

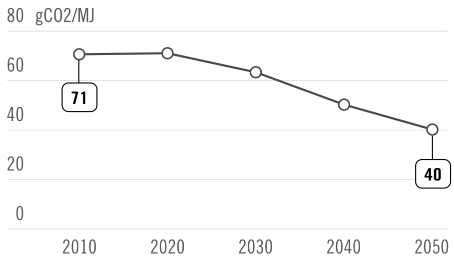
JAPAN - Balanced (BAL) Scenario

A1. National energy consumption and related emissions

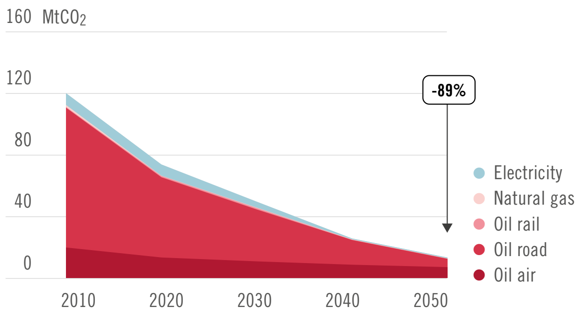
1.a Emission drivers



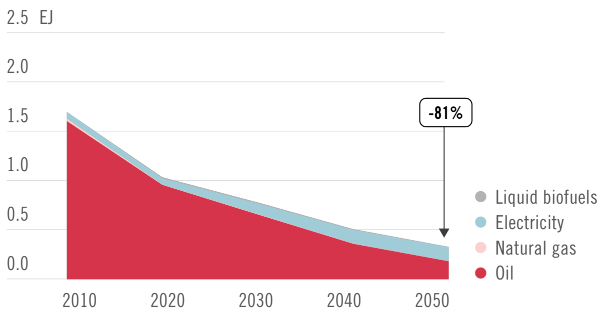
1.c Carbon content of energy



1.b CO_2 emissions



1.d Final energy consumption



A2. The pillars of decarbonization

Pillar 1
Energy efficiency

Individual Mobility

13

8 ← - 40%

000s pkm/cap

Energy intensity

1.0

0.4 ← - 50%

MJ/pkm

2010 2050

Pillar 2
Decarbonization of electricity and fuels

Carbon content of electricity

395

13 ← - 97%

gCO_2/kWh

Biofuel in blended fuels *

0 → + 2 pt

2

% blended fuels

** Liquid fuels and pipe gas*

Pillar 3
Shifting to low carbon fuels

Non fossil fuel energy **

4 → + 39 pt

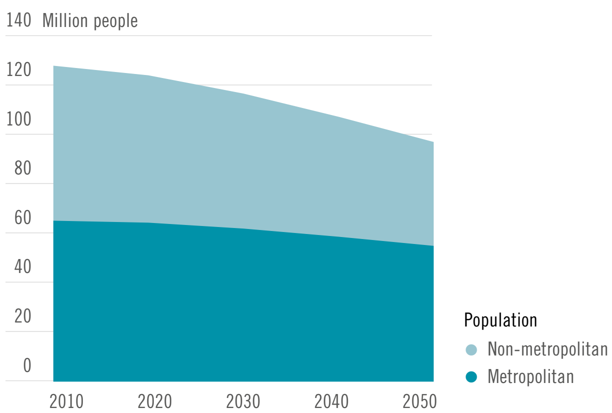
44

% of total energy

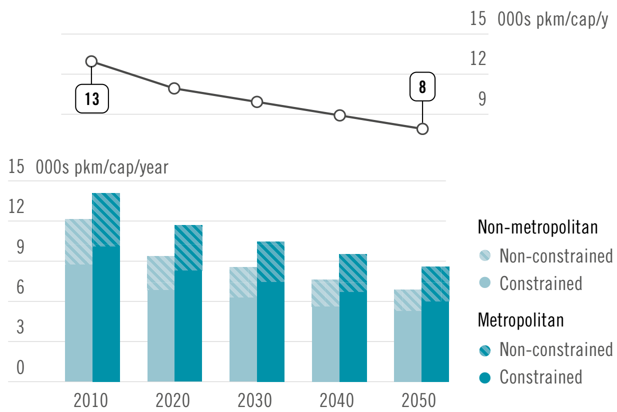
*** Integrating electricity, liquid and gaseous biofuels, hydrogen*

A3. Population and mobility

3.a Metropolitan and non-metropolitan population

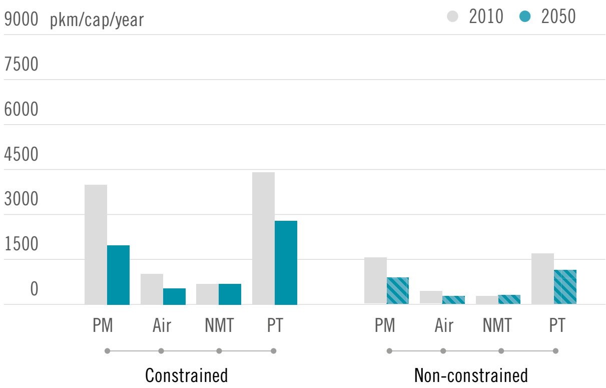


3.b Constrained and non-constrained mobility

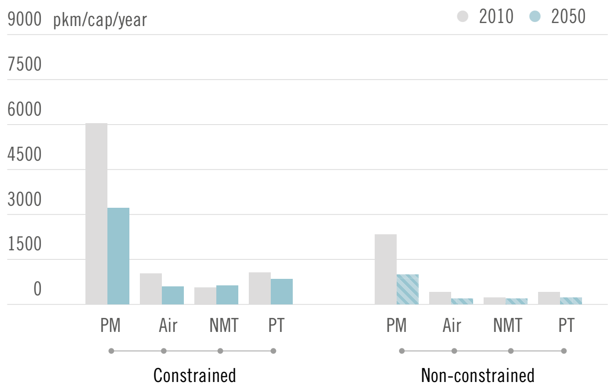


A4. Modal structure

4.a Metropolitan



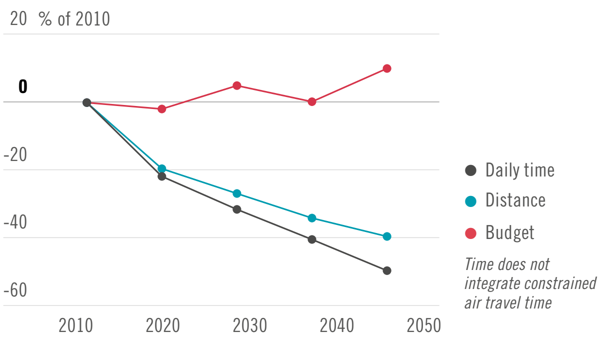
4.b Non-metropolitan



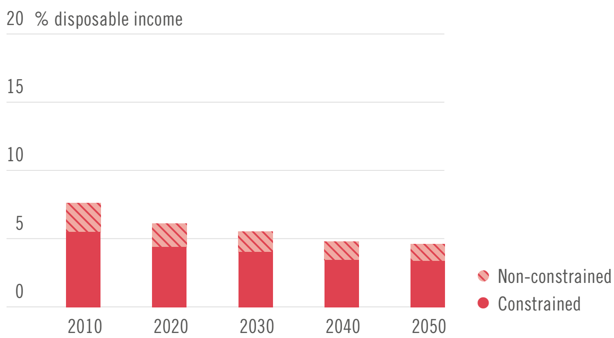
PM = Private Mobility (car and 2W), NMT = Non-motorized transport (walking, biking…), PT = Public transport (bus and rail)

A5. Mobility indicators

5.a Indicators for constrained mobility

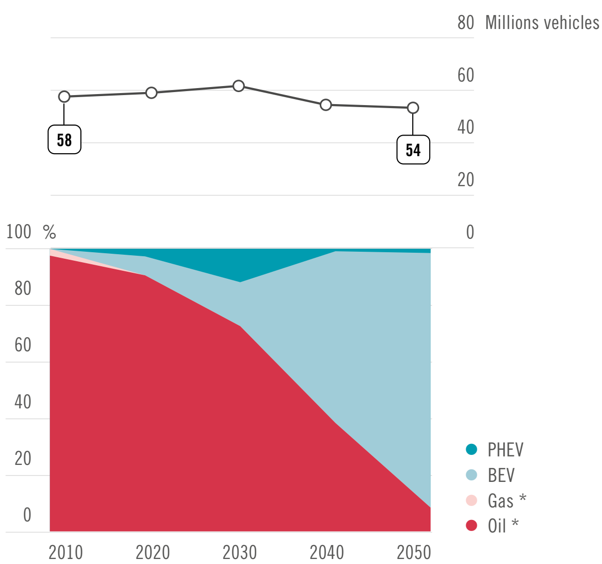


5.b Transport budget

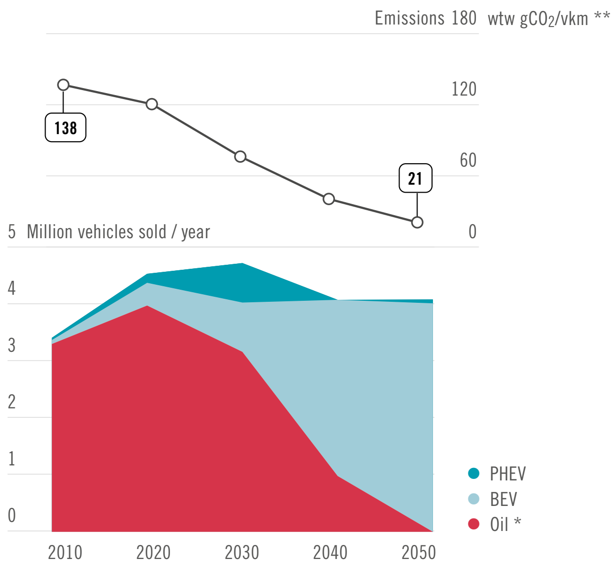


A6. Car mobility

6.a Car stock



6.b Car sales and related emissions



** "Oil" means thermal motorization fueled by liquids (gasoline, diesel, liquid biofuels); "Gas" means thermal motorization fueled by gas (natural gas, biogas)*

*** Emissions of average car sales is expressed in "well-to-wheel" gCO_2 per vehicle-km travelled*

References (in chapter 1)

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The Asia-Pacific Integrated Model (AIM) is a large-scale computer simulation model developed by the National Institute for Environmental Studies in collaboration with Kyoto University, Mizuho Information & Research Institute and several research institutes in the Asia-Pacific region. The AIM assesses policy options for stabilizing the global climate, particularly in the Asia-Pacific region, with the objectives of reducing greenhouse gas emissions and avoiding the impacts of climate change. *http://www-iam.nies.go.jp/aim/index.html*

The National Institute for Environmental Studies (NIES) was established in 1974 as the sole research institute for integrated, interdisciplinary research in the broad field of environmental research, to provide the scientific and technical basis for the environmental policy-making administration. To facilitate the implementation of both long-term and issue-driven environmental research, NIES conducts ten research programs focusing on climate change, sustainable material cycles, risk assessment and control of environmental chemicals, and other environmental research. NIES pursues high-level research based on a firm understanding of the interaction between nature, society, and life on our planet. *http://www.nies.go.jp/index-e.html*

DKB Information Systems, Fuji Research Institute Corporation, and IBJ Systems were merged into Mizuho Information & Research Institute Inc. (MHIR) in 2004. MHIR provides total solutions including consulting, systems integration, and outsourcing. In the field of consulting, MHIR provides solutions to a wide variety of customers from enterprises to ministries and other public offices, with experts in four distinct fields: "Society & Economy", "Information & Communication", "Science & Technology" and "Environment & Energy."
http://www.mizuho-ir.co.jp/english/index.html

The Institute for Global Environmental Strategies (IGES), established under an initiative of the government of Japan in 1998, is an international research institute conducting practical and innovative research for realizing sustainable development in the Asia-Pacific region. IGES research focuses on three issues of critical importance: climate change and energy, natural resource management, and sustainable consumption and production. IGES also serves as the secretariat for various international initiatives and research networks, actively contributing to policy formulation in the form of information sharing and policy proposals. *http://www.iges.or.jp/en/index.html*

The Institute for Sustainable Development and International Relations (IDDRI) is a non-profit policy research institute based in Paris. Its objective is to determine and share the keys for analyzing and understanding strategic issues linked to sustainable development from a global perspective. IDDRI helps stakeholders in deliberating on global governance of the major issues of common interest: action to attenuate climate change, to protect biodiversity, to enhance food security and to manage urbanization, and also takes part in efforts to reframe development pathways.

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