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Toranomon Hills Forum

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# Innovations of products, services and social systems, and their impacts on climate change mitigation measures

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RITE
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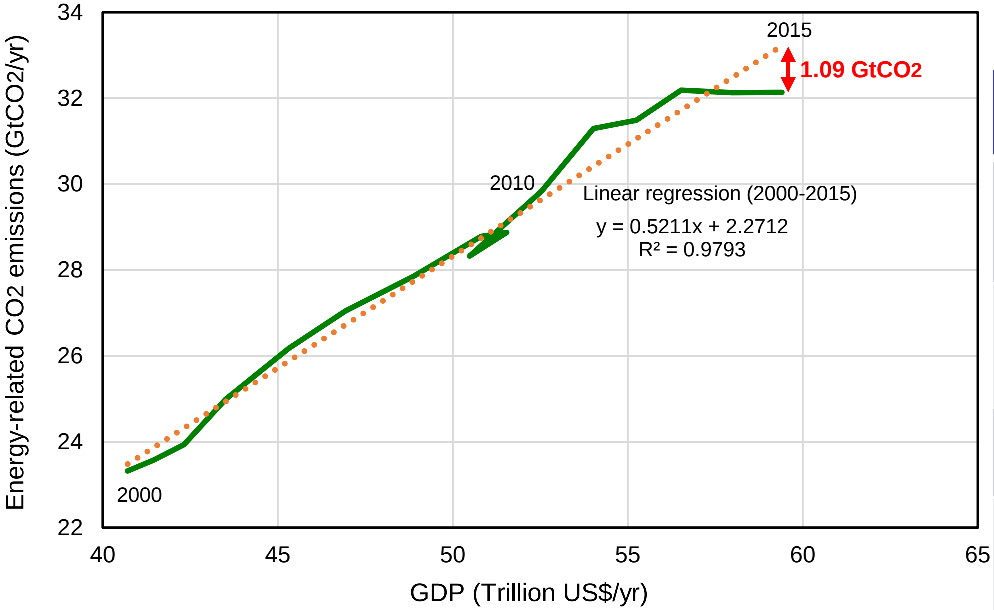
# Contents

# 1. Empirical analyses for decoupling

# Global GDP growth vs CO2 emission






GDP (Trillion US2005$/yr)

Source) IEA
Note) GDP: Real, MER, in 2005 price

Source) http://www.rite.or.jp/system/events/akimoto_ALPSII_2017.pdf

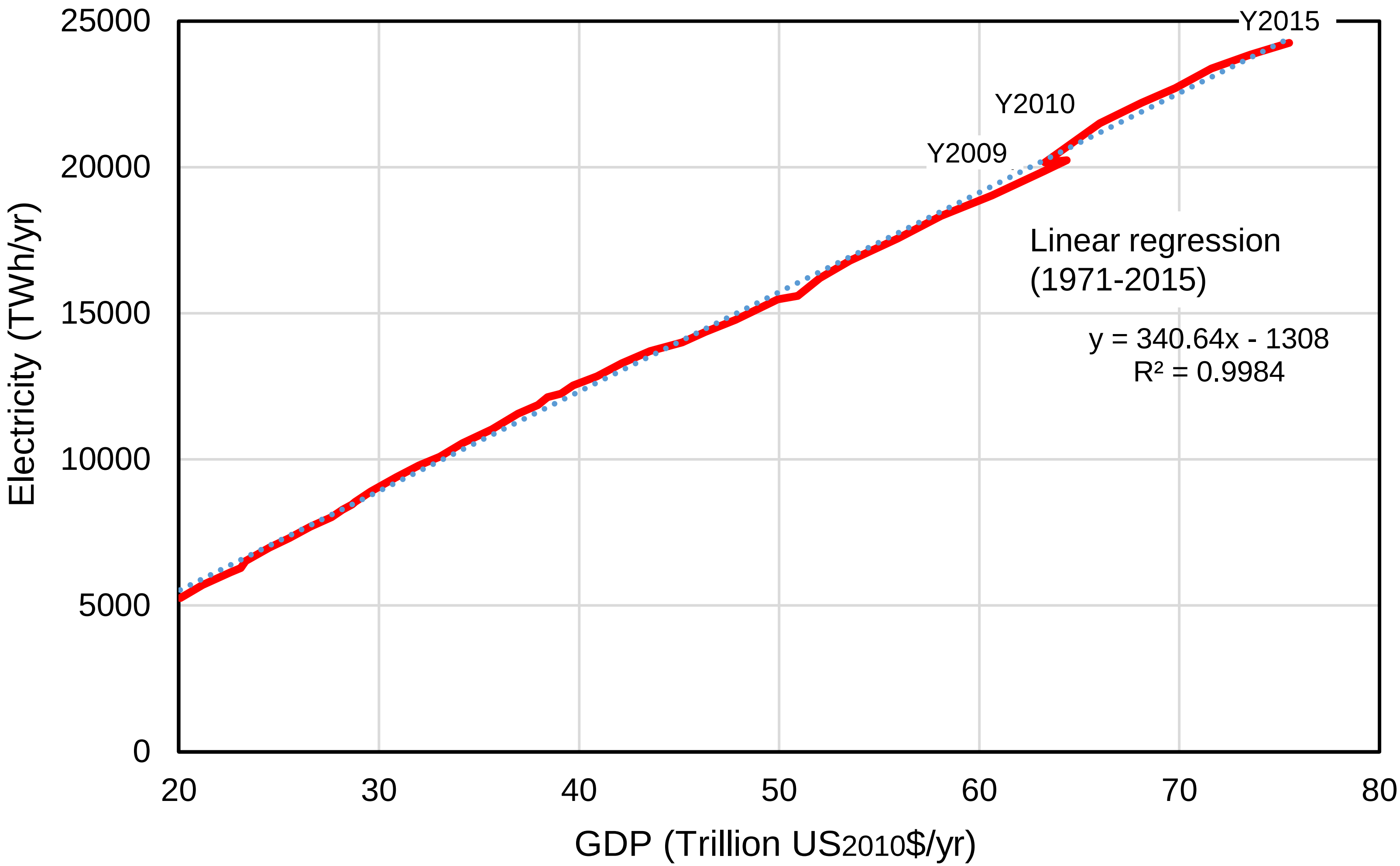
## Factors of emission reduction in 2015 from the long-term trend

| Factor | 2015 reduction effects | Explanation |
| --- | --- | --- |
| Reductions in global iron production | about 250 $MtCO_2$/yr | Decrease in global iron production of about 100 Mt (particularly in China) |
| Reductions in global cement production | about 50 $MtCO_2$/yr | Decrease in global cement production of about 170 Mt (particularly in China) |
| Increase in shale gas in the U.S. | about 220 $MtCO_2$/yr | Shifts from coal to shale gas economically in the U.S. |
| Expansion of renewable energies | about 160 $MtCO_2$/yr | Higher expansions by 1.2%/yr point compared with the average annual expansion rate |
| Reduction in $CO_2$ emissions of Japan | about 40 $MtCO_2$/yr | Due to Fukushima-daiichi nuclear power accident, the emission in Japan increased as a trend. |

- **Fundamentally, a strong positive correlation between global GDP and $CO_2$ emissions is observed. Although global emissions were almost flat between 2013 and 2016, this can be regarded as adjustments of larger emissions growth in 2009-13 to the long term trend.**
- **Major contributions of this leveling were production adjustment of steel or cement sectors mainly in China, and a shift to shale gas in U.S. Impact of increase in renewable energy diffusion seemingly is relatively small.**
- **Global $CO_2$ emission is in upward trend again in 2017 and 2018.**
- **Prospect for decreasing global $CO_2$ emission is not so optimistic.**

# Global GDP v.s. electricity consumption



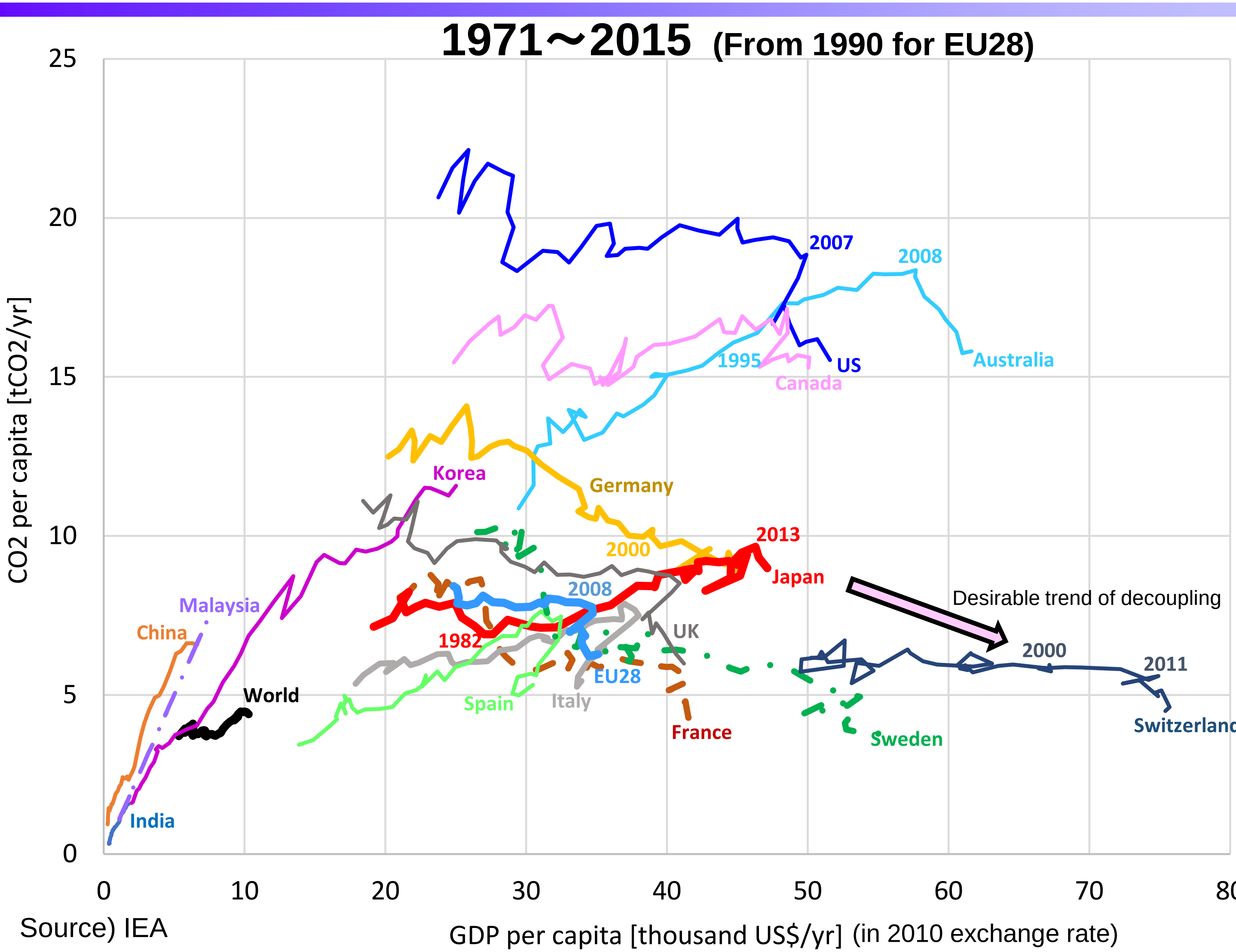



Source) IEA, 2017 Note) GDP: Real, MER, in 2010 price

**The relationship between the global GDP and electricity consumption shows a strong linearity. Energy particularly electricity play an important role for economic activities after the industry revolutions.**

# GDP vs $CO_2$ emissions in major countries: overview





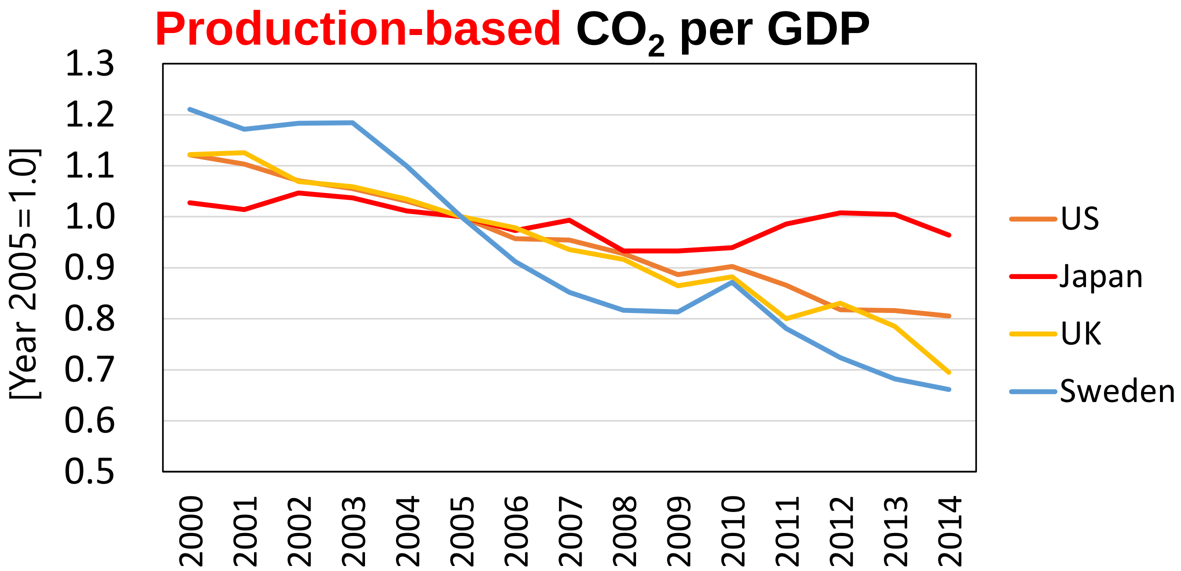

Source) IEA

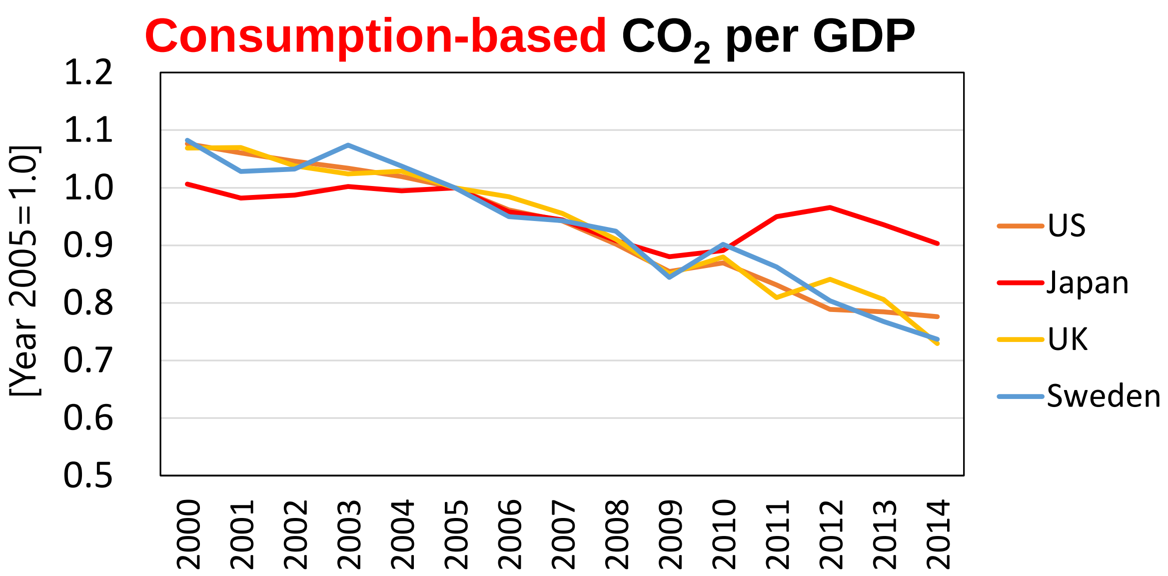
- Several developed countries seem to follow decoupling trend, i.e. GDP increases while $CO_2$ emission decreases.
- On the other hand, $CO_2$ emissions per capita vary widely among countries with similar GDP per capita, due to heterogeneity in their land area and industrial structure.
- Switzerland, Sweden and France are thought to be on the leading edge of decoupling trend because of their small $CO_2$ emissions despite their relatively high GDP. But their emission levels have conventionally been low due to high ratios of hydro and nuclear.
- Increase of historical $CO_2$ emissions by China is much steeper than forerunners.
- Detailed investigation is required to conclude whether these trends are truly contributing to global decoupling, considering international sharing of industry and domestic industrial structure.

**Although several developed countries appear to be following decoupling trend as a whole, it is hard to reach a clear conclusion as various and complicated factors are entangled.**

# Per-GDP CO2 Emission in US, UK, Sweden and Japan: Production-base v.s. Consumption-base

Source: estimated by RITE



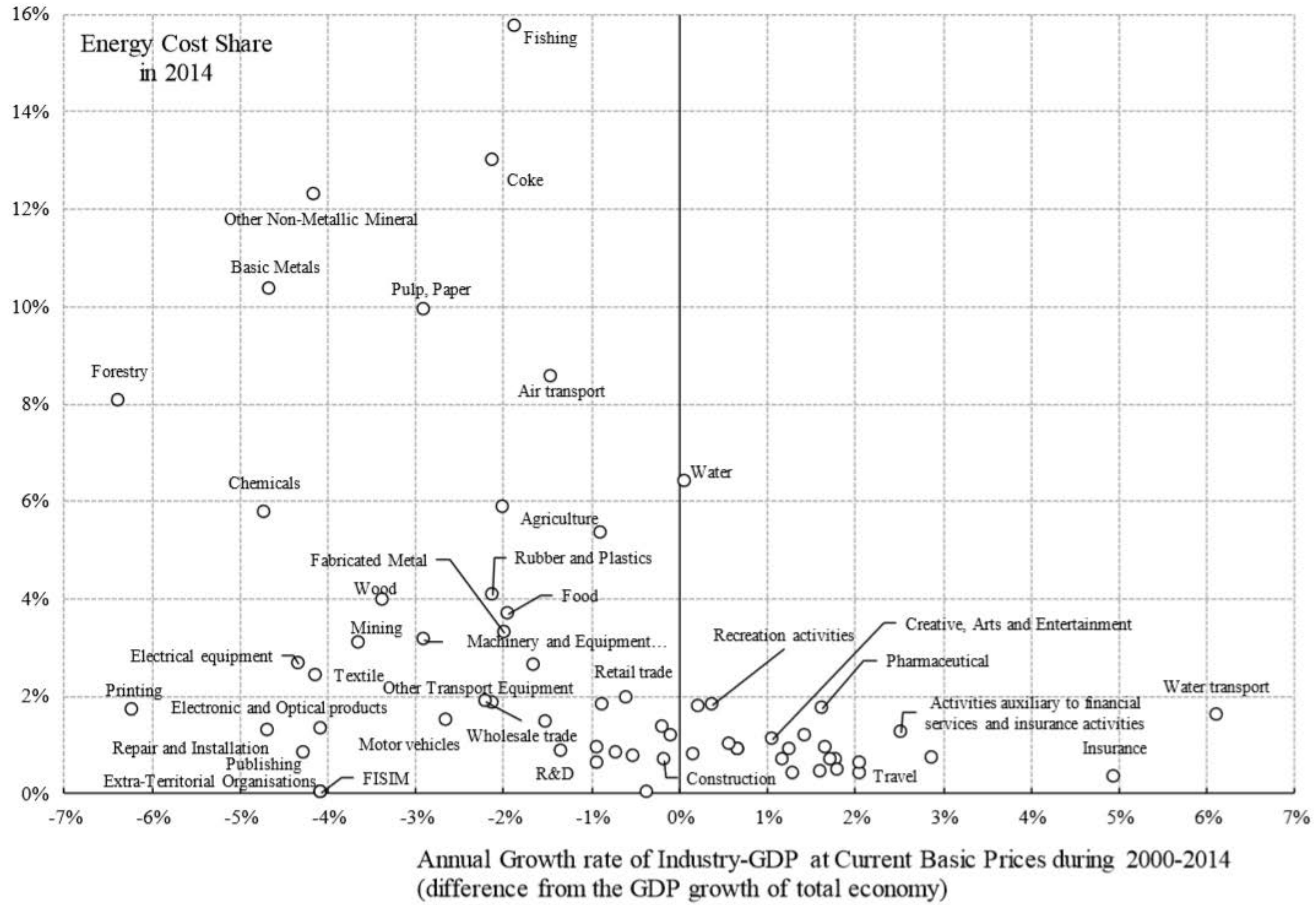

- In terms of the production-based $CO_2$ emissions per GDP, the degrees of improvement of the four countries differs greatly.
- However, concerning the consumption-based emissions, the improvement rate of the four countries does not differ that much when excluding the impact of Japan's emission increase due to the shutdown of nuclear power generation after the Fukushima Daiichi nuclear power accident during the Great East Japan Earthquake.

Note: 2010 local currency base

# Energy cost share (2014) vs Economic growth (2000-14) of industrial sectors in UK

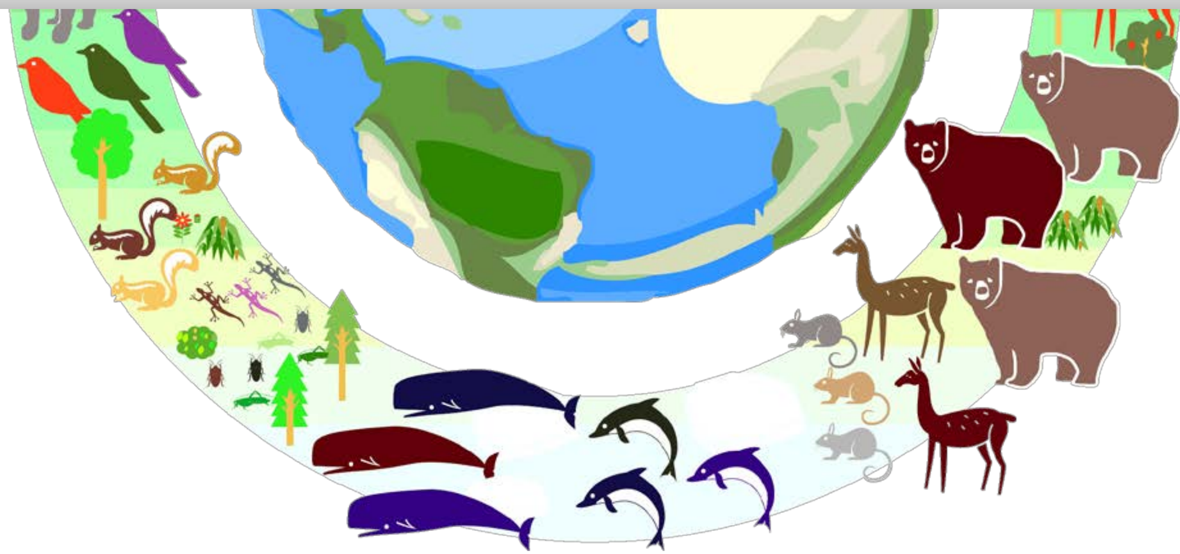


Source: K. Nomura, https://www.dbj.jp/ricf/pdf/research/DBJ_RCGW_DP60.pdf (in Japanese)



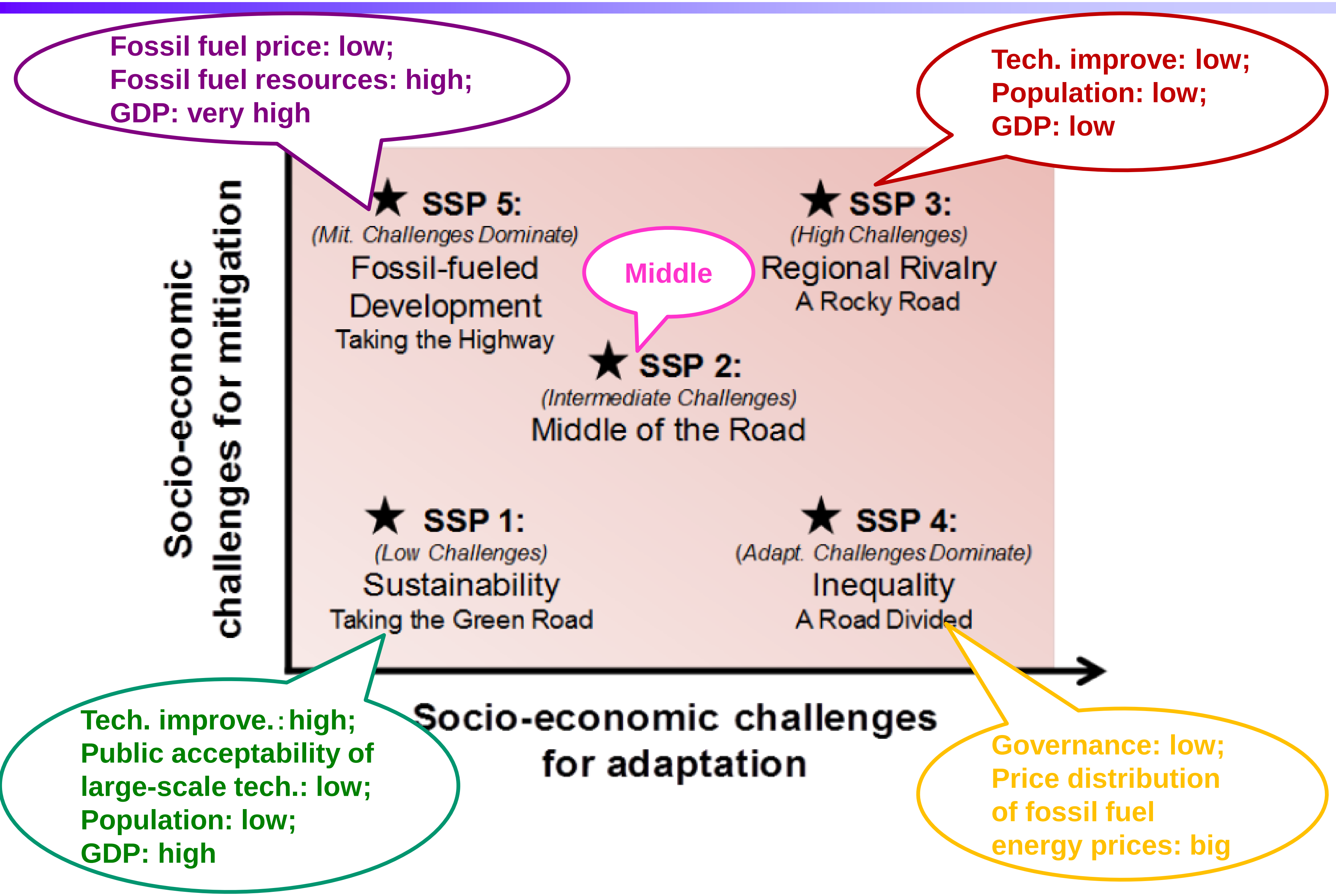

**The industrial sectors having high share of energy costs in the total costs showed relatively small growth rate between 2000 and 2014. These sectors shifted ~~to~~ outside the UK according to the analyses of consumption-based $CO_2$ emissions.**

# 2. Toward Green Growth



# Overview of Shared Socioeconomic Pathways (SSPs)



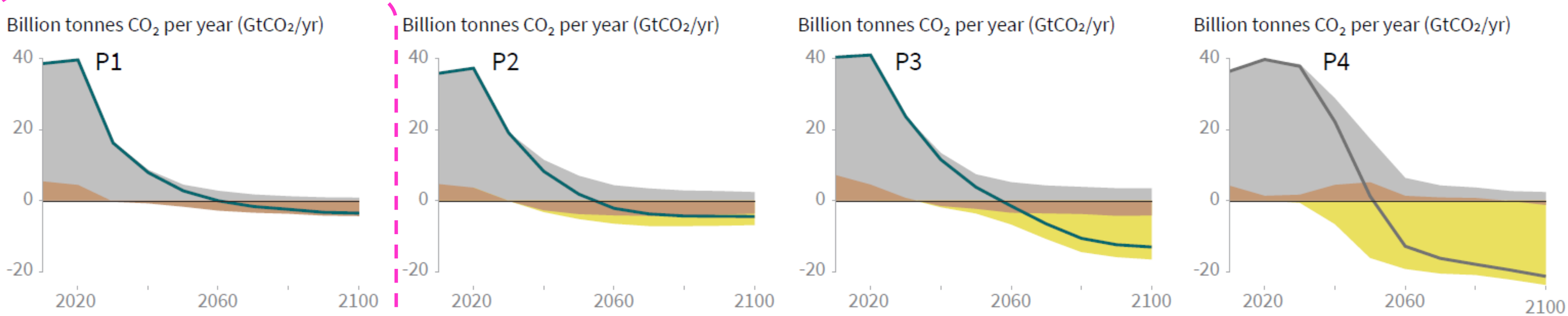


# Categorization of deep emission reduction scenarios for below 1.5 °C



Fossil fuel and industry · AFOLU · BECCS

Source) IPCC SR15




P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

**Much lower energy demand scenarios than those of SSP1**

**SSP1**

**SSP2 (Middle scenario)**

**SSP5**

**Low** ⟷ **High**

**Final energy demands**

- **Low energy demand is induced autonomously on economic principle through technological and social innovations**
- **Low carbon prices (business based measures even without strong climate polices)**

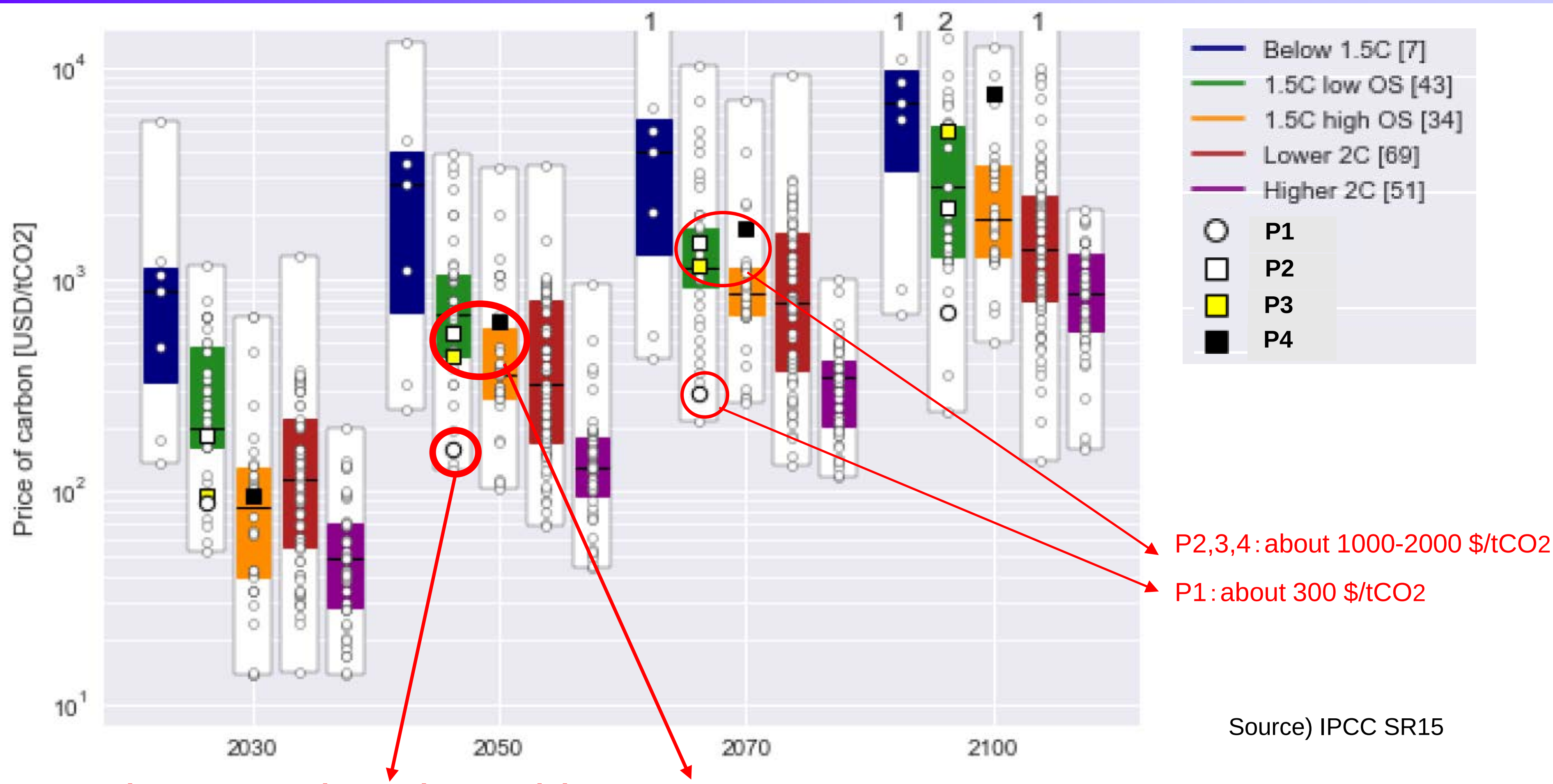
✓ **The total risk management is important, and various kinds of technologies play their own roles.**

✓ **On the other hand, opportunities of innovations in end-use technologies, induction of low energy demands, and their impacts on total climate change mitigation should be more focused. (P1)**

- **High carbon prices (harmonization among nations are required to avoid carbon leakage)**
- **Large-scale deployments of CDR, e.g., CCS, BECCS, DACS, are required.**

# $CO_2$ marginal abatement costs (carbon price) for 1.5 °C and 2 °C targets






Source) IPCC SR15

**P1 (Low energy demand scenario): about 150 $/tCO2**

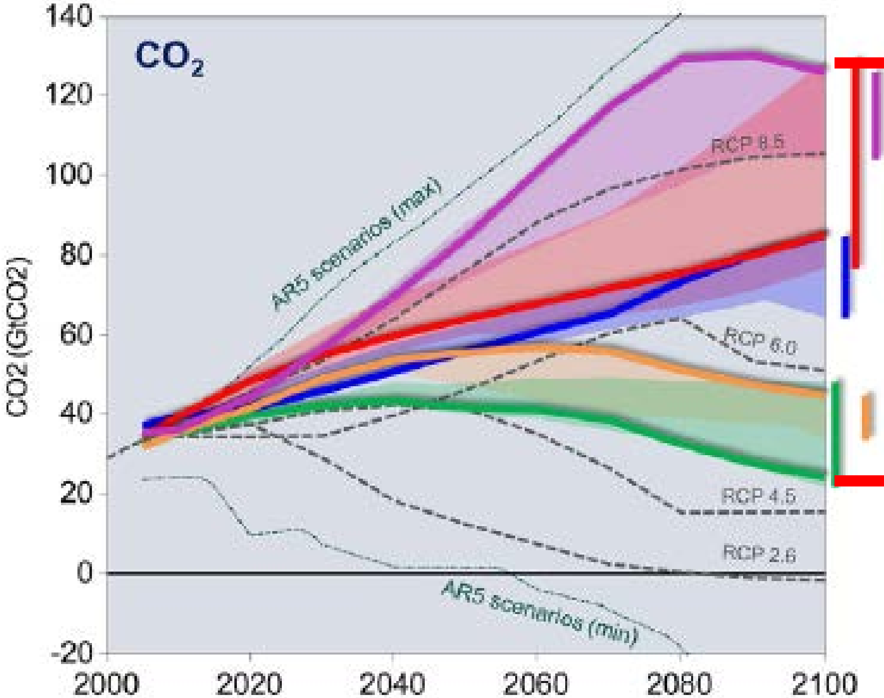
**P2, P3, P4：over 400 $/tCO2**

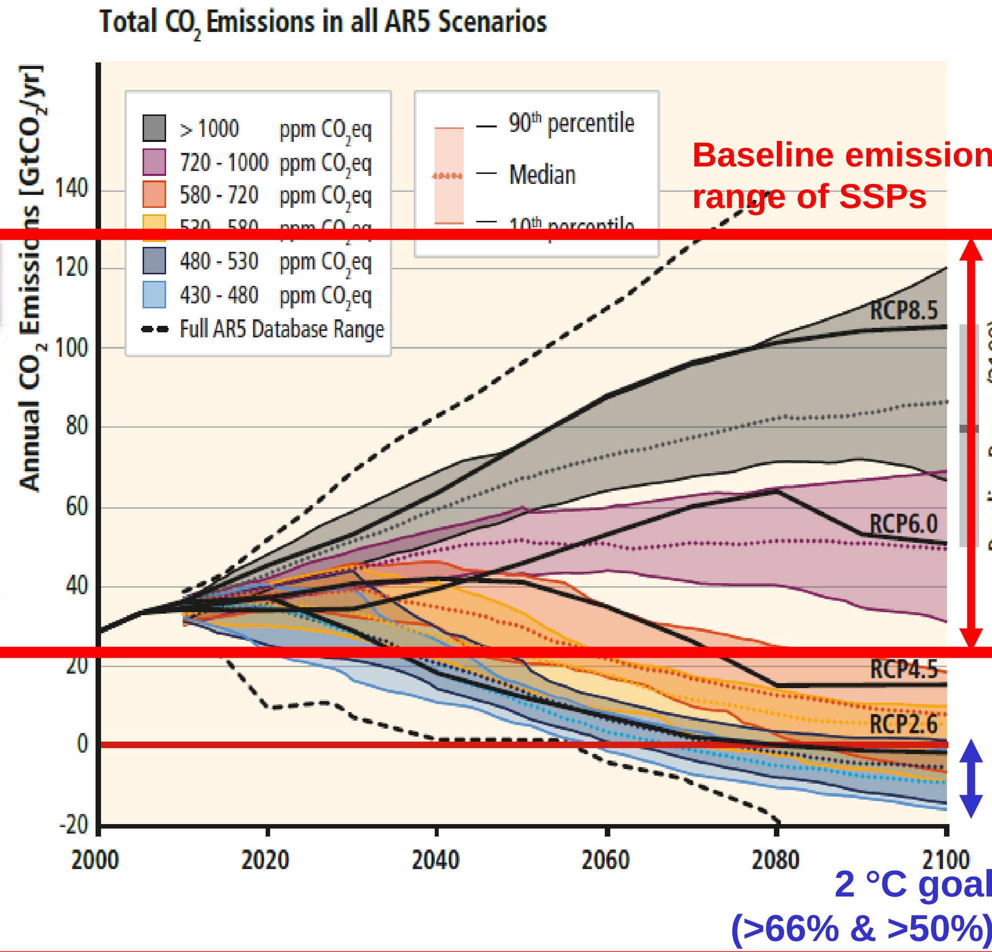
✓ **The carbon price under the P1 (Low energy demand) scenario is much lower than others (P2-4).**

**Note) The carbon prices for 1.5 °C consistent pathways are estimated to be about 3-4 times higher than those for 2 °C pathways according to the IPCC SR15.** Some models do not obtain the feasible results for 1.5 °C pathways.

# Range of baseline emission pathways based on different socioeconomic scenarios and pathways for 2 °C target

**SSP: Shared Socioeconomic Pathway (used for IPCC scenario analyses etc.)**

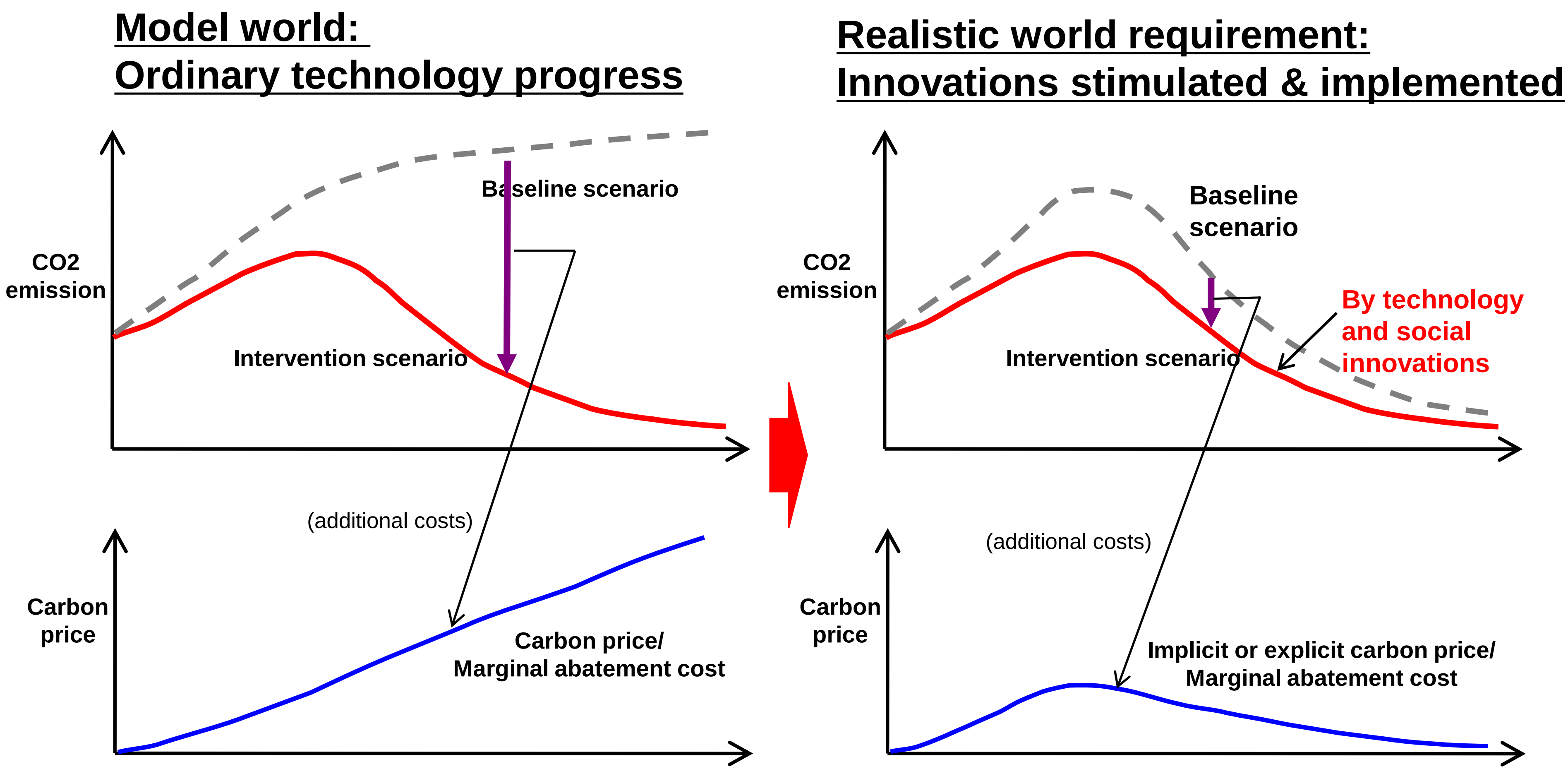



- There are large uncertainties in baseline emissions due to uncertainties in socioeconomic development. The uncertainty range is much larger than that for different target levels of temperature (e.g., ±0.5 °C, that is, 1.5 to 2.5 °C target).
- It is significant to achieve such low emissions with net negative costs through technological and social innovations.

# Image of standard scenarios by models and scenarios required for deep cuts in a real world






**High carbon prices of over 100$/t$CO_2$ in real price are unlikely to be accepted globally in a real world. Technology and social innovations which will bring low (implicit or explicit) carbon prices (including coordination of secondary energy prices) are key to achieve deep emission cuts.**

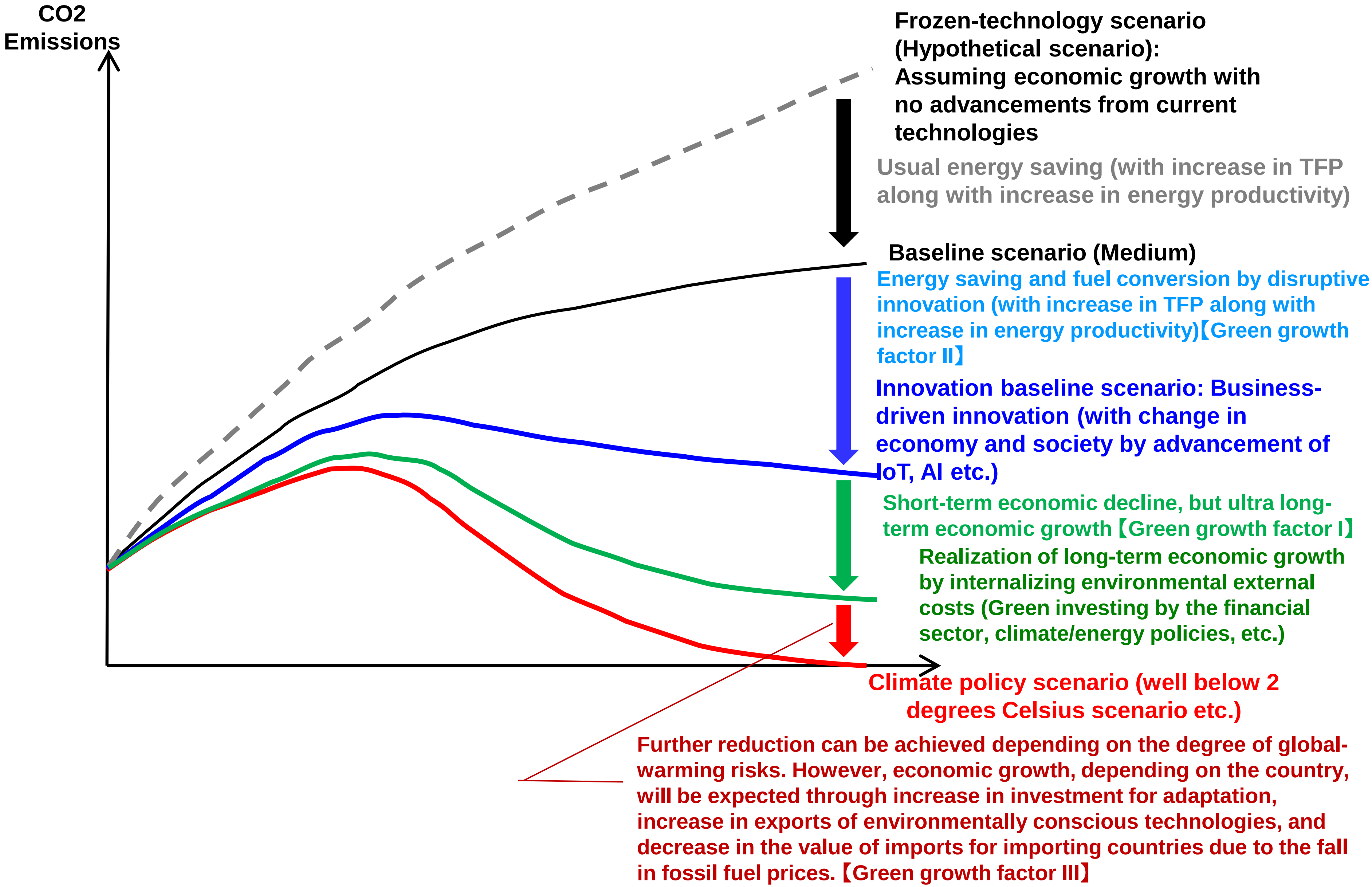
# Opportunities for Green Growth



| | Opportunity for Green Growth | Explanation |
|---|---|---|
| **[I] Long-term green growth worldwide** | **Internalization of damage cost by climate change impact currently regarded as external costs by GHG emissions** | e.g. Governmental regulations, standards, labelling or implicit carbon pricing, voluntary action or internal carbon price by firms, ESG investment by financial organizations. Internalizing environmental external costs may lead to larger growth than not internalizing them in long-term perspective, although causing short-term slowing of economic growth. **【Presuming worldwide emissions reduction】** |
| **[II] Middle-to long-term green growth worldwide** | **Achievement of innovation that induces GHG reduction** | Achievement of innovation that promotes economically independent emissions reduction (e.g. progress of sharing economy with IT or AI), as well as measures to support the innovation (e.g. policies for promoting private investment such as corporate tax break, realization of good economic circumstances, or elimination of less necessary regulations) **【Effect of realizing innovation may expand worldwide even without global emissions reduction effort】** |
| **[III] Middle-to long-term green growth in specific countries** | **Income growth of the countries by increase in export of superior technologies or products for mitigating global warming to overseas** | **【Presuming worldwide emissions reduction. Green growth opportunities for countries with higher capability of environmentally-friendly technology development】** |
| | **Income growth of the countries by decrease in import through lower fossil fuel price caused by $CO_2$ emissions reduction effort** | **【Presuming worldwide emissions reduction. Green growth opportunities for countries with higher dependence on imported fossil fuel】** |
| | **Economic growth opportunities by replacing fossil fuel resource import with capital-intensive technologies** | Opportunities for improving total factor productivity by enhancing resource productivity, albeit potentially decreasing capital productivity or energy productivity **【Green growth opportunities for countries with higher dependence on imported fossil fuel and higher capability of environmentally-friendly technology development】** |

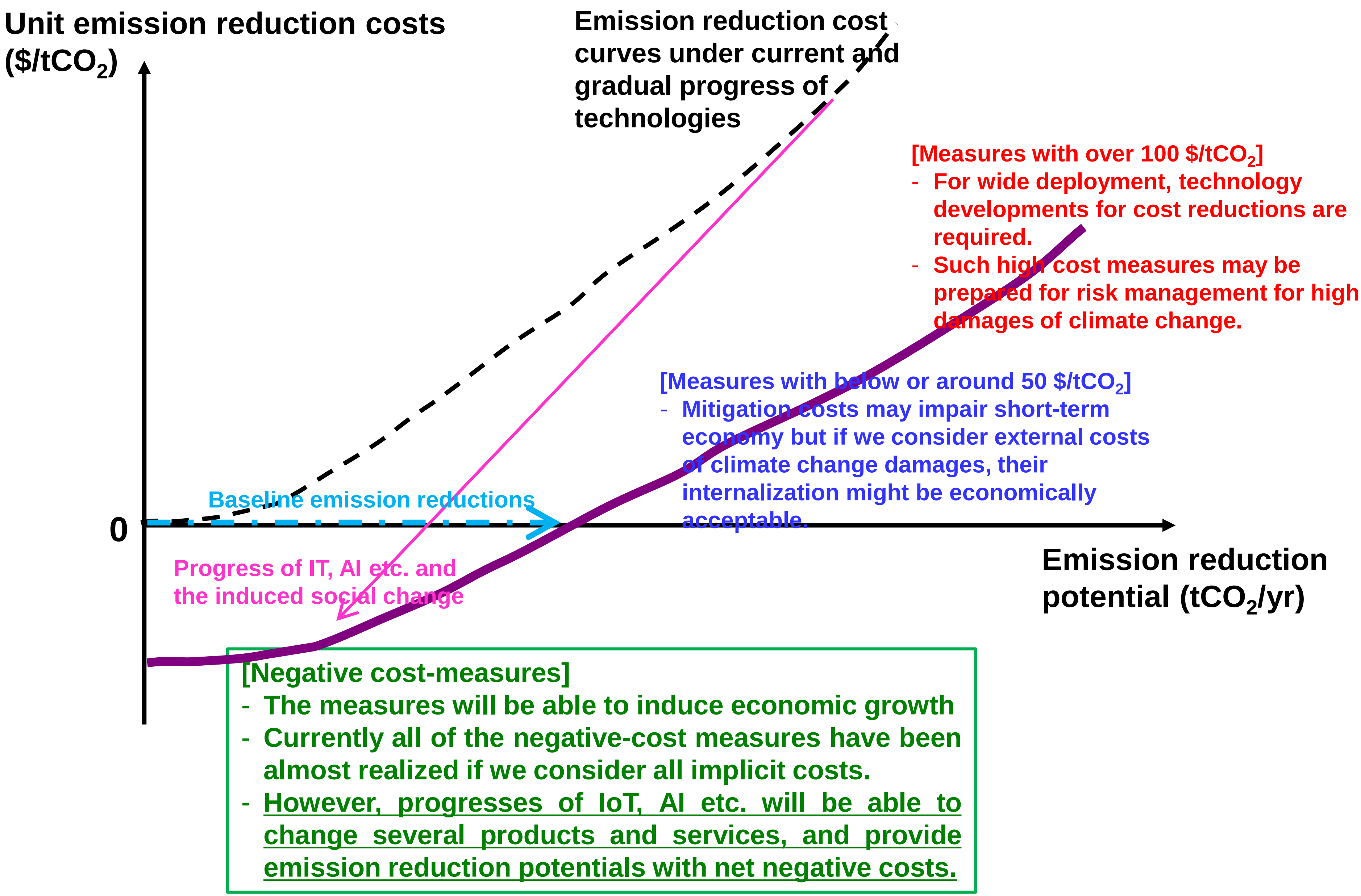
# Image of $CO_2$ emissions of Green Growth Scenarios





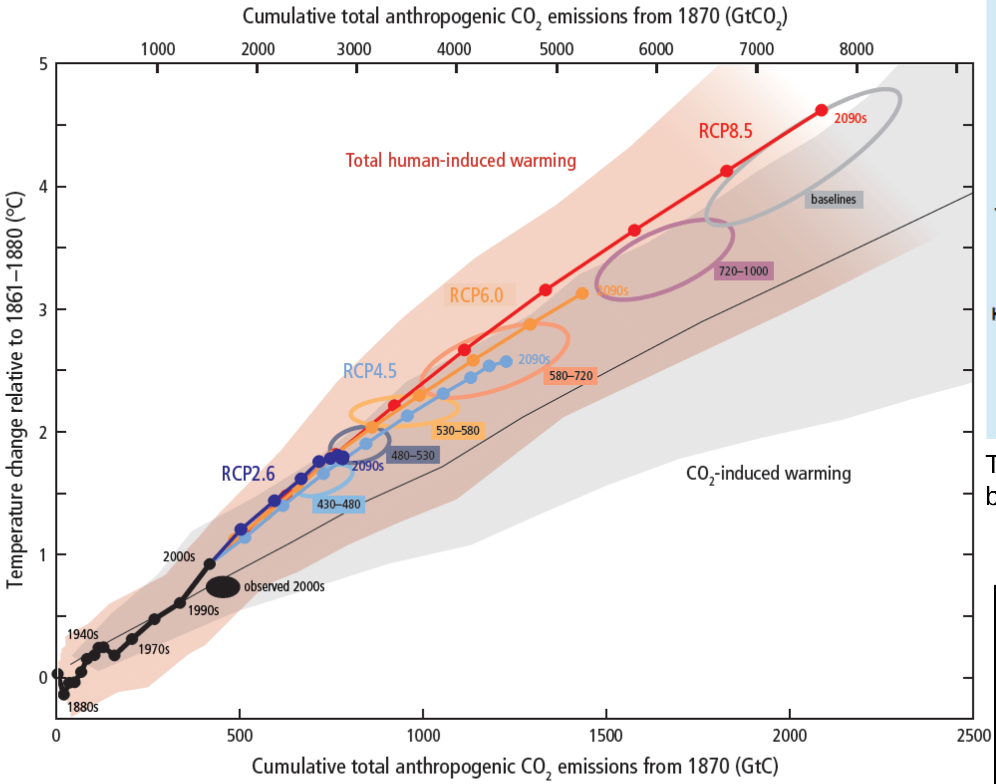
# Image of shift of emission reduction cost curves



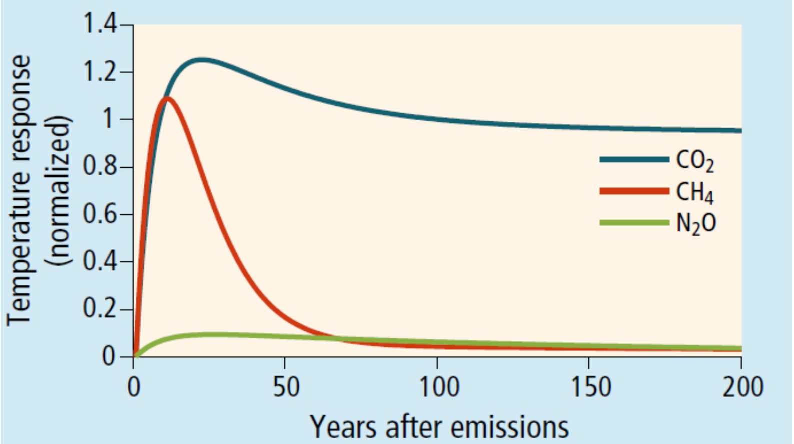


# Relationship between cumulative $CO_2$ emissions and temperature rise and uncertainties in climate sensitivity






Source) Synthesis report of IPCC AR5




Temperature response to emissions in 2010; the responses are normalized by the amount of contribution of CO2 emission after 100 years past

## Uncertainties in Climate sensitivity (IPCC)

| | **Equilibrium climate sensitivity** Likely range ("best estimate") |
|---|---|
| **Before IPCC WG1 AR4** | **1.5–4.5°C (2.5°C)** |
| **IPCC WG1 AR4 (2007)** | **2.0–4.5°C (3.0°C)** |
| **IPCC WG1 AR5 (2013)** | **1.5–4.5°C (no consensus)** |
| **IPCC WG3 AR5 (MAGICC) (2014)** | **2.0–4.5°C（3.0°C）[Based on the AR4]** |

**- [Long-term] Approximately linear relationship between cumulative $CO_2$ emissions and temperature rise can be observed. Nearly net zero $CO_2$ emissions are necessary for the stabilization of global temperature at any level.**
**- [Near- & mid-term] Emission pathways for the long-term zero emissions have wide ranges due to uncertainties in climate sensitivity.**

# Implications in relation to the Paris Agreement

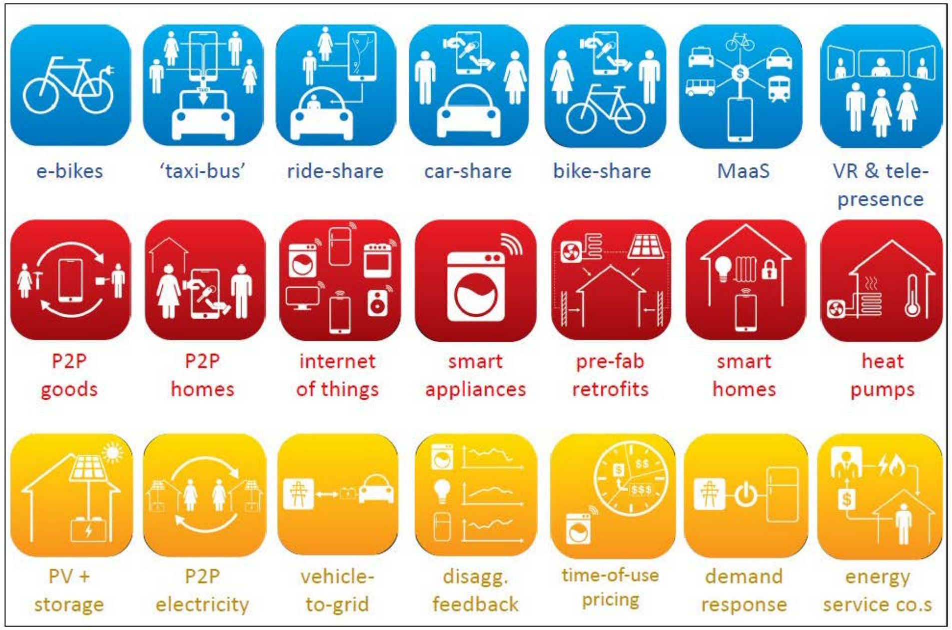


- The Paris Agreement (PA) specifies long-term targets such as keeping temperature rises to well below 2℃ relative to pre-industrial levels, pursuing 1.5℃, and achieving net zero GHG emissions in the latter half of the 21st century.
- Global Stocktake every 5 years (the same process continues.)
- At the COP24 held in December 2018, a detailed rule book of PA was agreed. Differentiated reviewing between developed and developing countries was not framed, whereas pushing for raising ambition of the NDCs was not framed either.
- There are few measures of filling the gap between the long-term targets and actual emissions. A strong emission abatement measure by a single country or a few countries without wider international cooperation would not work well, because of industrial transferring to overseas and carbon leakage.
- Green growth (generating multiple synergies with the SDGs) is essential in order to reach the PA's long-term targets while properly managing total risks. For this purpose, technological progress and social transformation on the energy demand side, induced by innovations such as IT and AI, can offer significantly important opportunities.

# 3. Potential drastic changes of energy demands induced by progresses of AI, IoT etc.


# Disruptive Innovations of End-use Technologies






Source: C. Wilson (IIASA)

**Disruptive innovations of end-use technologies such as IoT, AI, will be able to induce:**

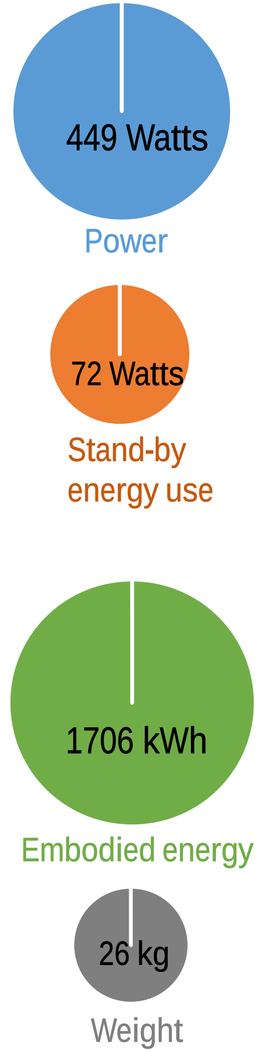
1) **Shift from atomized to connected**
2) **Shift from ownership to user-ship**
3) **Sharing economy & circular economy**

**Human society will be able to continue economic growth and resolve many social issues through building highly integrated systems of Cyberspace (virtual) and Physical space (real)**


Source: Government of Japan (Cabinet Office)

# Innovations in end-use technologies through IT and AI, and the induced social changes


Source：IIASA




- **Energy consumption is not our purpose, but is just a phenomenon accompanying with consumption of goods and services, which is conducted for our welfare increase. Energy embodied in goods and services must be taken into account.**
- **The end-use products and services will usually diffuse rapidly, and the embodied energy and $CO_2$ may decrease rapidly.**

Operation ratio of automobiles is about 5%. The large room for the improvement exists by the achievement of fully autonomous cars.


**There are large opportunities to achieve social changes and to increase energy efficiency through fully autonomous cars, food systems, etc. which can be induced by innovations of IoT, AI etc.**

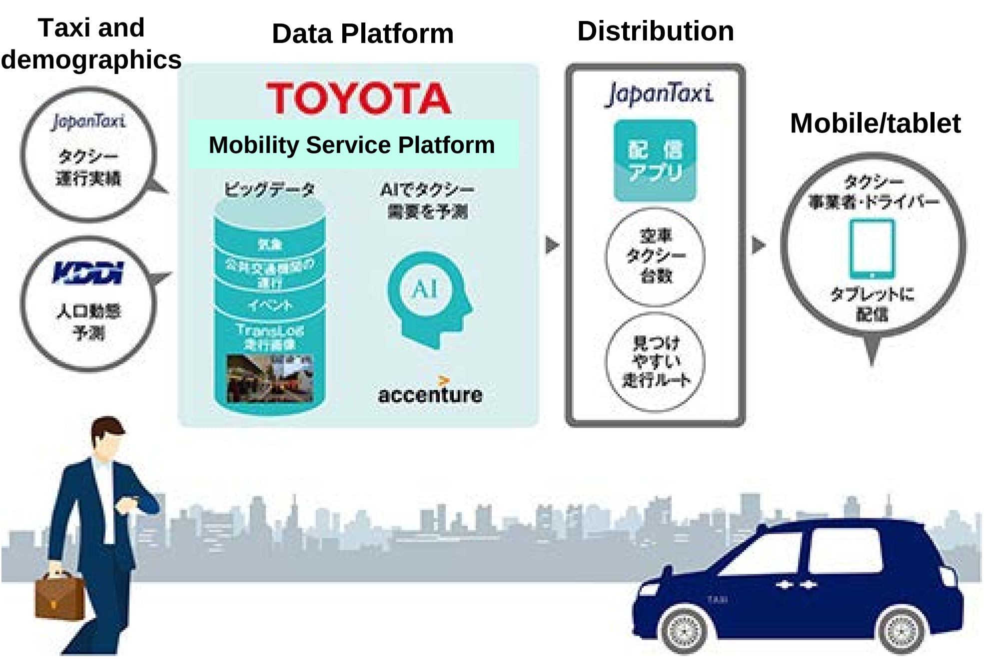
# Demand projection using AI and big data




Source: Japan Weather Association https://www.jwa.or.jp/news/2018/02/post-000984.html

- Food
- Taxi's dispatch
- Clothing
- Books
- Office sharing, etc.

**There are many opportunities of efficiency improvement**



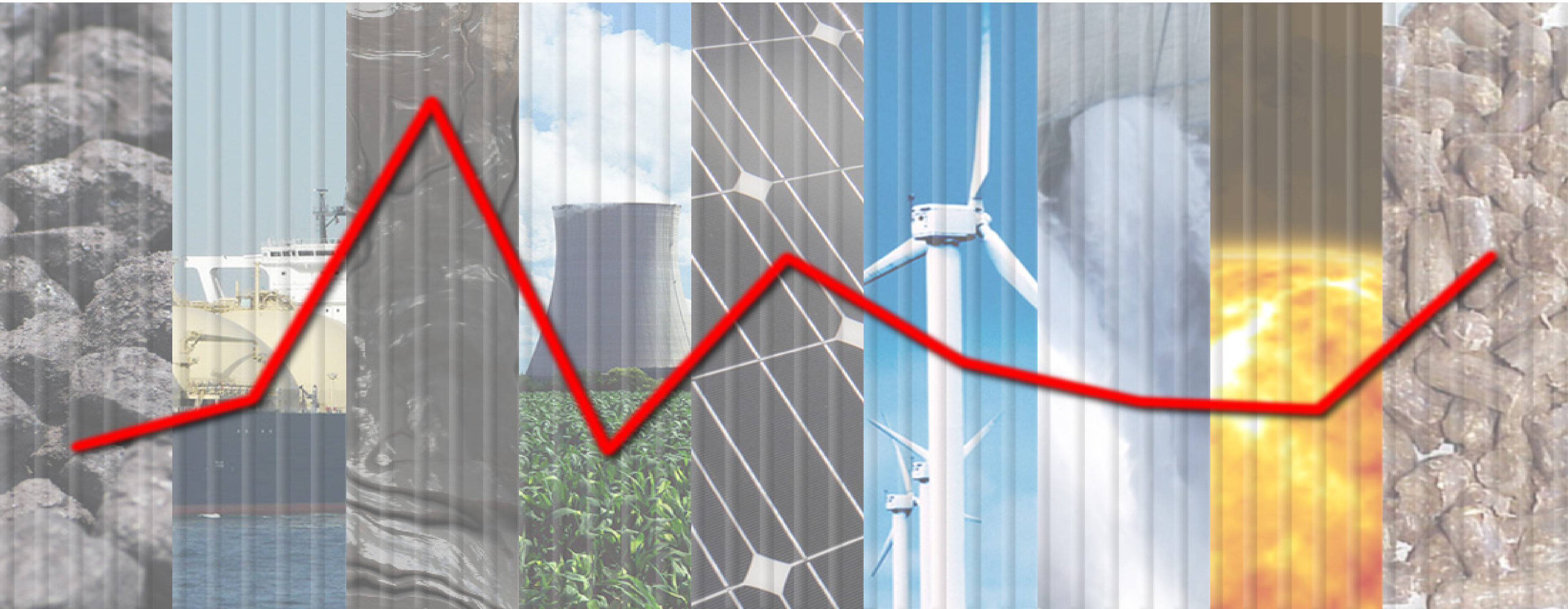

Source： http://www.atmarkit.co.jp/ait/articles/1803/12/news043.html

✓ **The key point is that large $CO_2$ emission reductions are not achieved if consumer welfare is thereby largely decreased, but are achieved autonomously on economic principle by innovations of AI etc.**

✓ **They do not directly aim at energy saving or $CO_2$ emission reduction, but contribute to the large reductions indirectly throughout lifecycle.**

**⇒ Big opportunities for green growth**

# 4. Scenario analyses for the Long-term target of the Paris Agreement: Impacts of car- & ride-sharing



# Energy Assessment Model: DNE21+

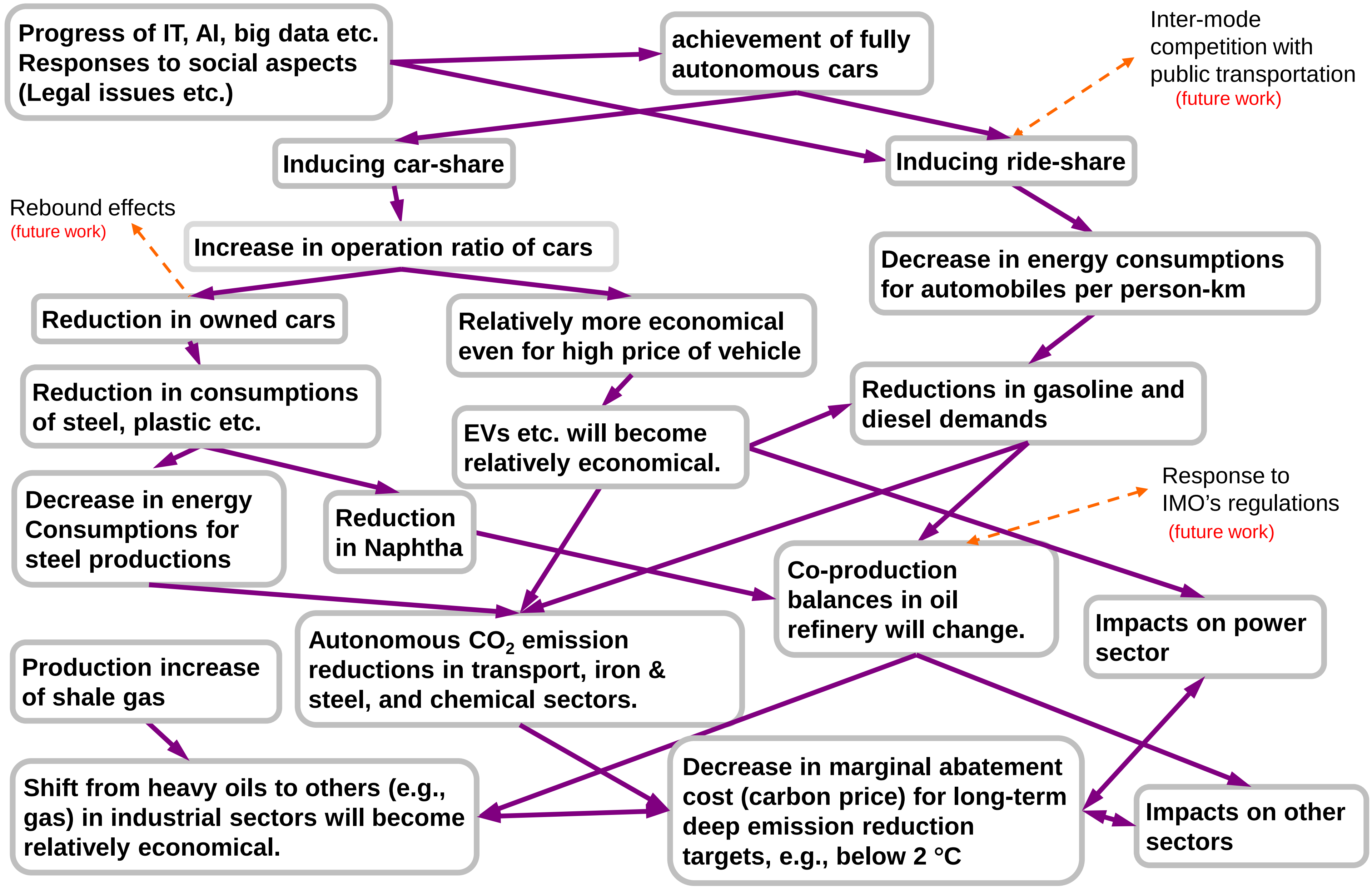


- Linear programming model (minimizing world energy system cost)
- Evaluation time period: 2000-2100
  **Representative time points: 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2070, 2100**
- World divided into 54 regions
  **Large area countries are further divided into 3-8 regions, and the world is divided into 77 regions.**
- Bottom-up modeling for technologies both in energy supply and demand sides (about 300 specific technologies are modeled.)
- Primary energy: coal, oil, natural gas, hydro&geothermal, wind, photovoltaics, biomass and nuclear power
- Electricity demand and supply are formulated for 4 time periods: instantaneous peak, peak, intermediate and off-peak periods
- Interregional trade: coal, crude oil, natural gas, syn. oil, ethanol, hydrogen, electricity and $CO_2$
- Existing facility vintages are explicitly modeled.

**- The model has regional and technological information detailed enough to analyze sectoral measures. Consistent analyses among regions and sectors are obtained.**

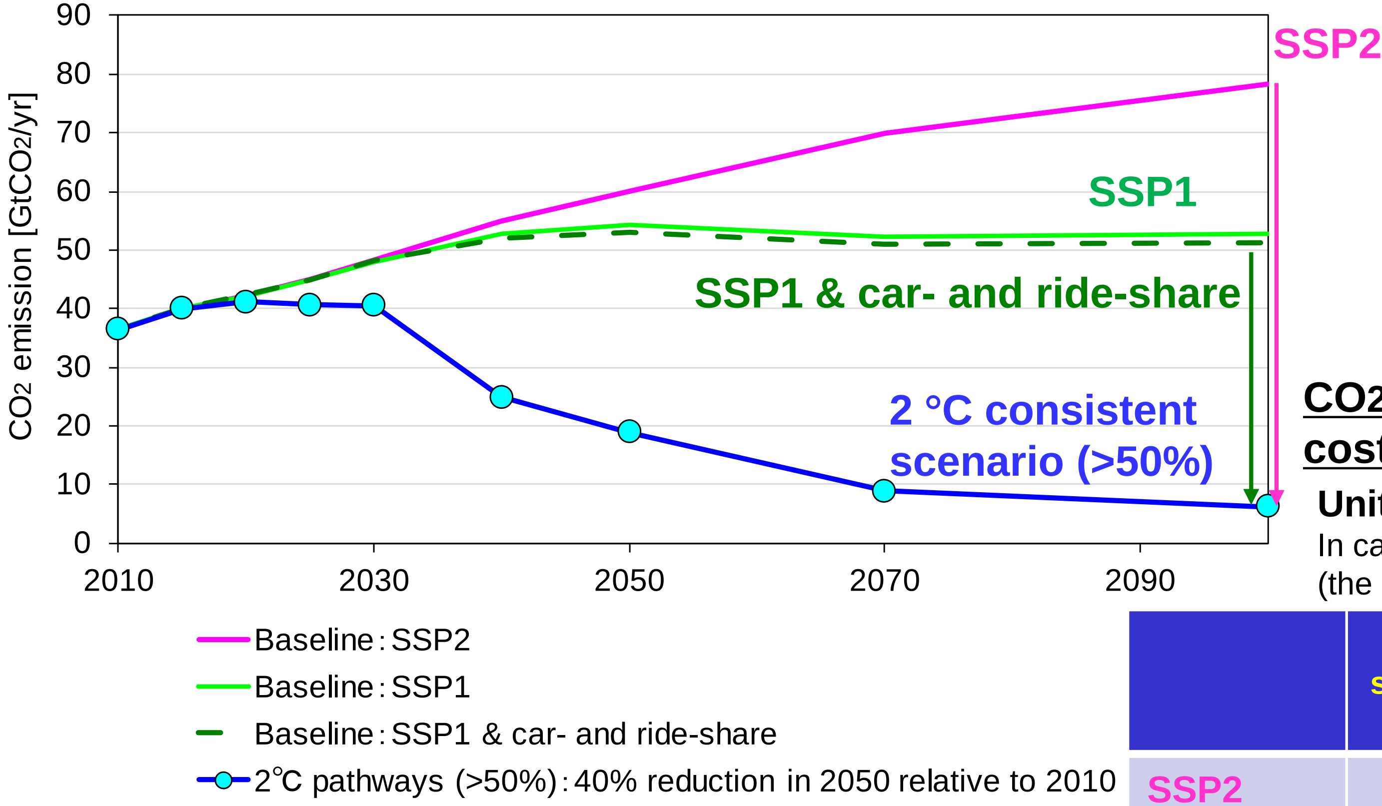
# Image of scenario analyses on the impacts of fully autonomous cars and the induced car- and ride-share based on the innovations of IT, AI etc.





# Global emission pathways and $CO_2$ marginal abatement costs for 2 °C goal






Source) estimated by using a global energy and climate change mitigation model, DNE21+, developed by RITE

**The marginal abatement costs for the scenario of SSP1 & car- and ride-share are much lower than those for the SSP2 scenario.**

## $CO_2$ marginal abatement costs for 2 °C pathways

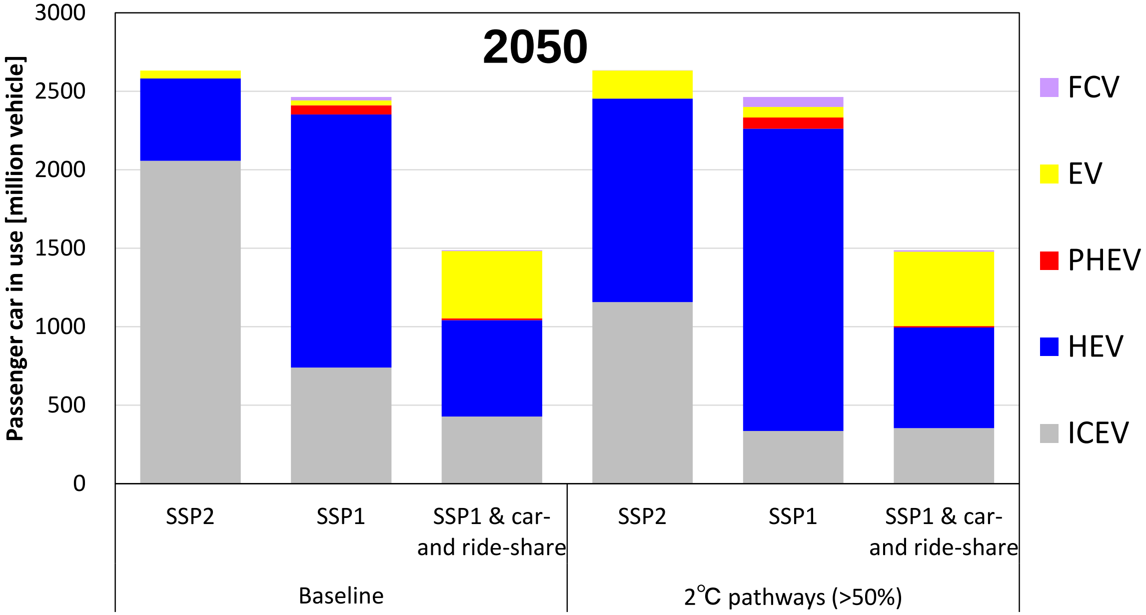
**Unit: $/t$CO_2$ (real price)**

In case of uniform carbon price (the least cost case)

| | Consistent scenario with IPCC SR15 | 2050 | 2100 |
|---|---|---|---|
| SSP2 (Middle scenario) | P3 | 154 | 269 |
| SSP1 | P2 | 165 | 187 |
| SSP1 & car- and ride-share | P1 | 126 | 185 |

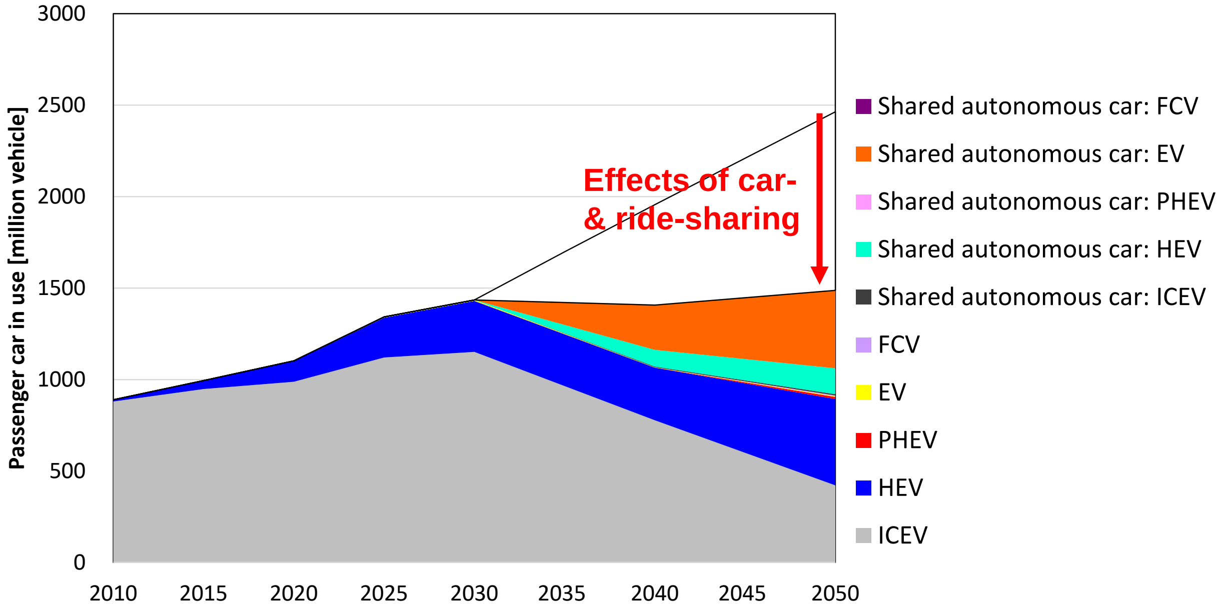
# Global automobiles owned: impacts of sharing induced by fully autonomous cars





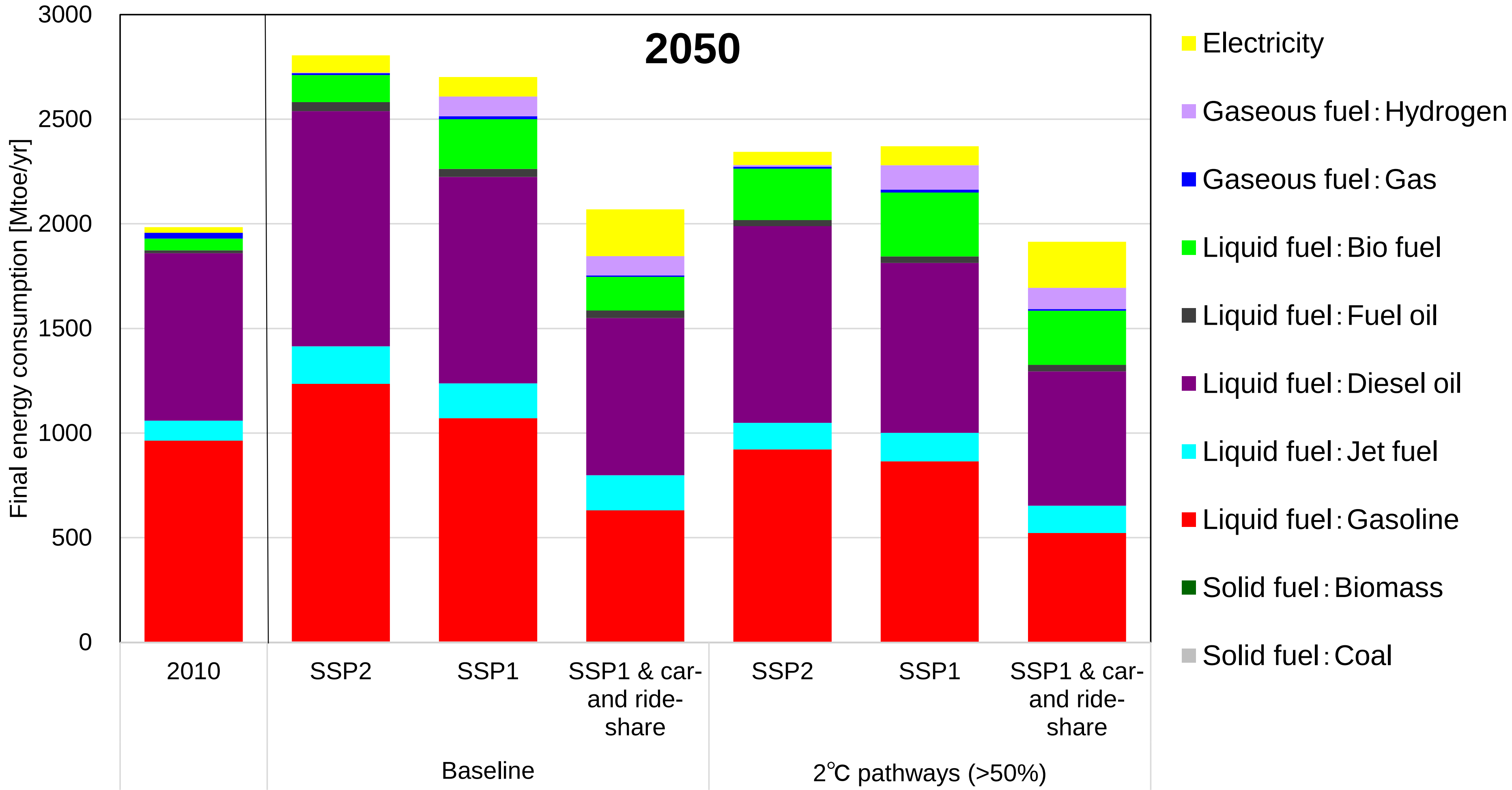

**SSP2 ⇒ SSP1**
**Cost reductions in environmental friendly cars, e.g., hybrid vehicle, PHEV, EV, FCV for SSP1 induce that these cars are more economically.**

**SSP1 ⇒ SSP1 & car- and ride-share**
**The sharing brings higher operation ratios and induces economic travels even with high price cars, and EVs diffuse relatively more widely even in Baseline scenario.**



# Global energy consumption in transport sector



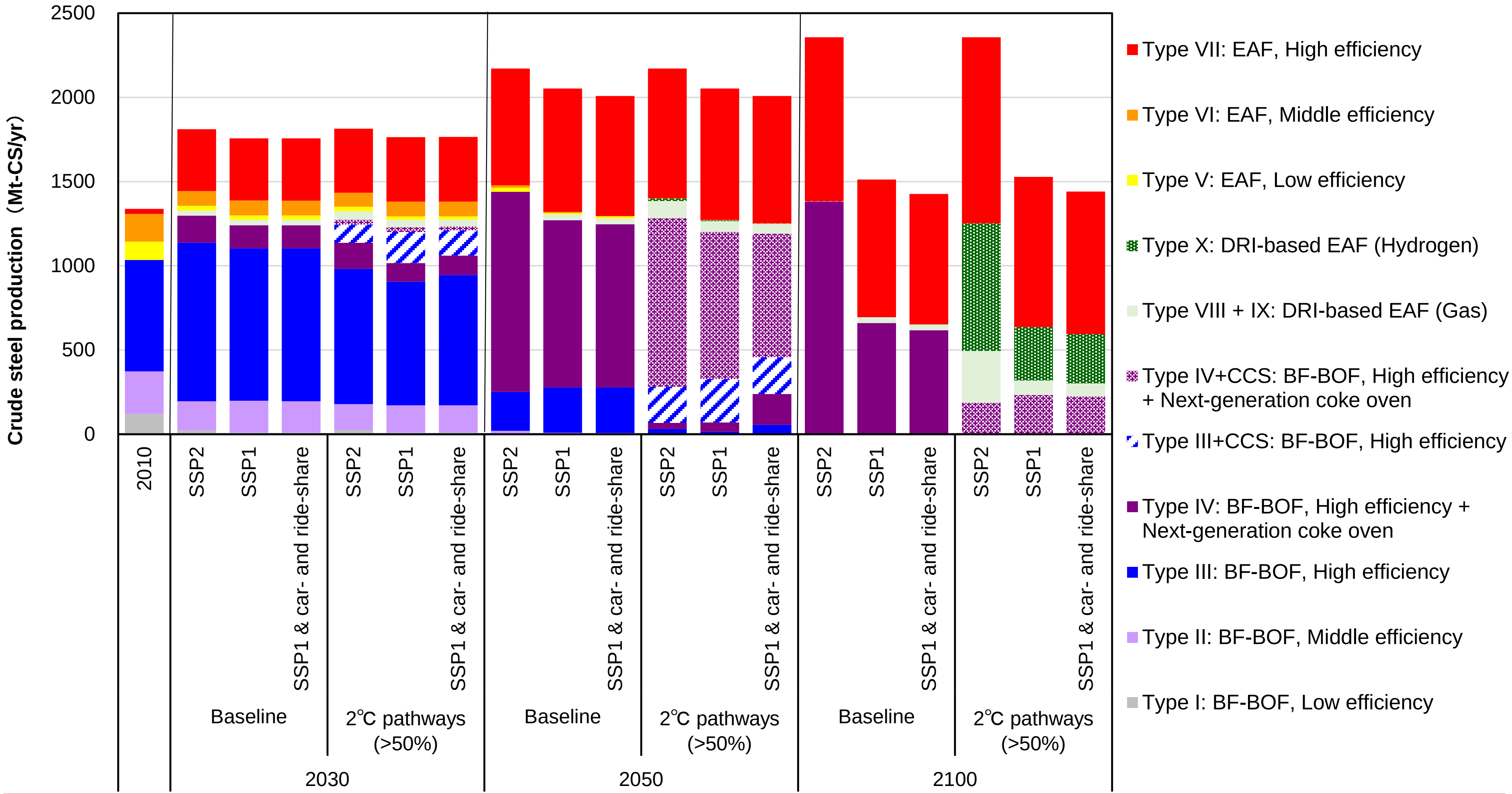



**- Future price reductions of cars induce energy consumption decrease in transportation sector** (including all mobilities in this figure) **in baseline scenarios. (SSP2⇒SSP1)**

**･Much larger impacts of car- & ride-sharing induced by fully autonomous cars can be observed in transportation sectors. (SSP2, SSP1⇒SSP1 & car- and ride-sharing)**

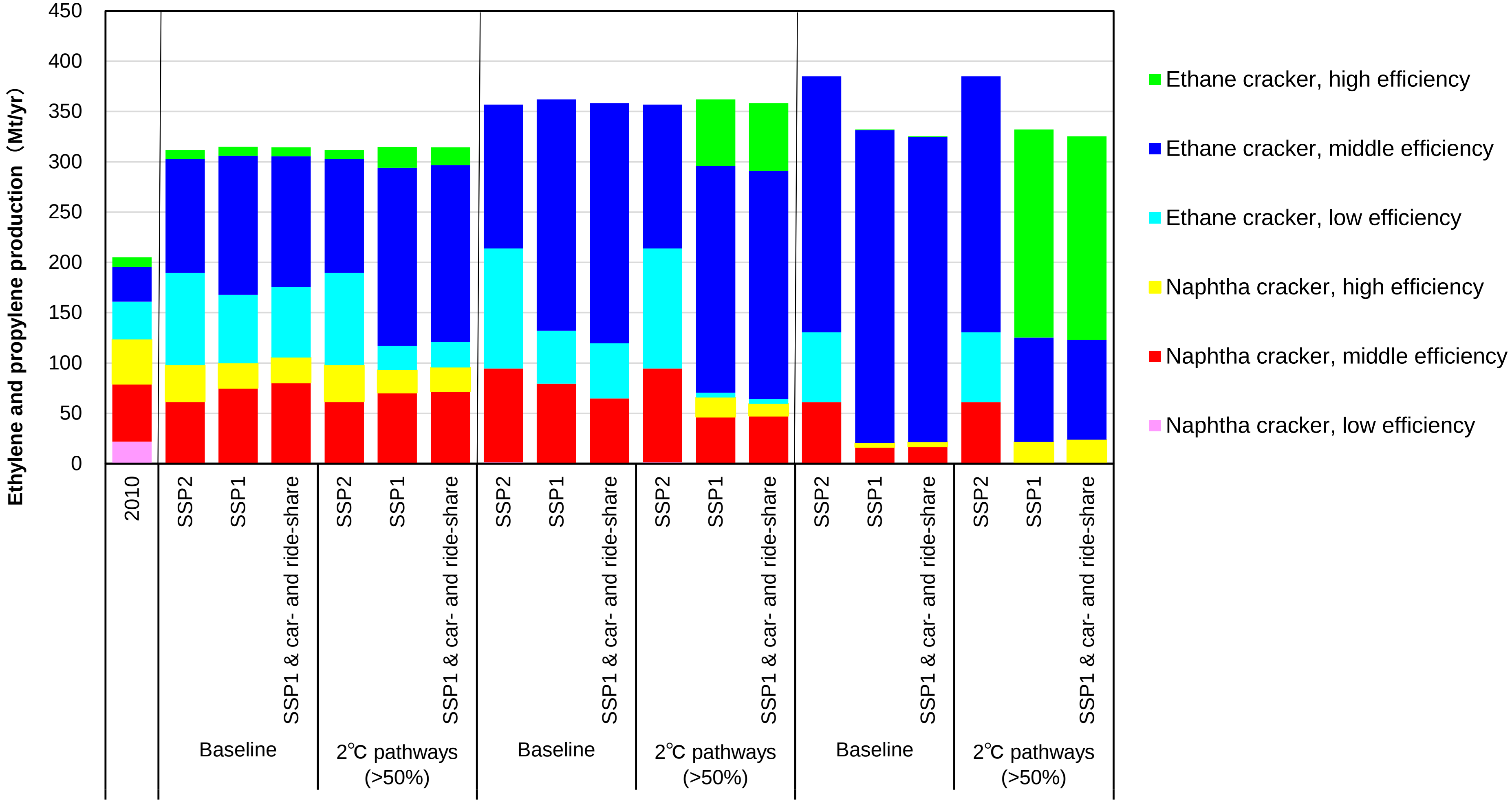
# Global crude steel production by technology





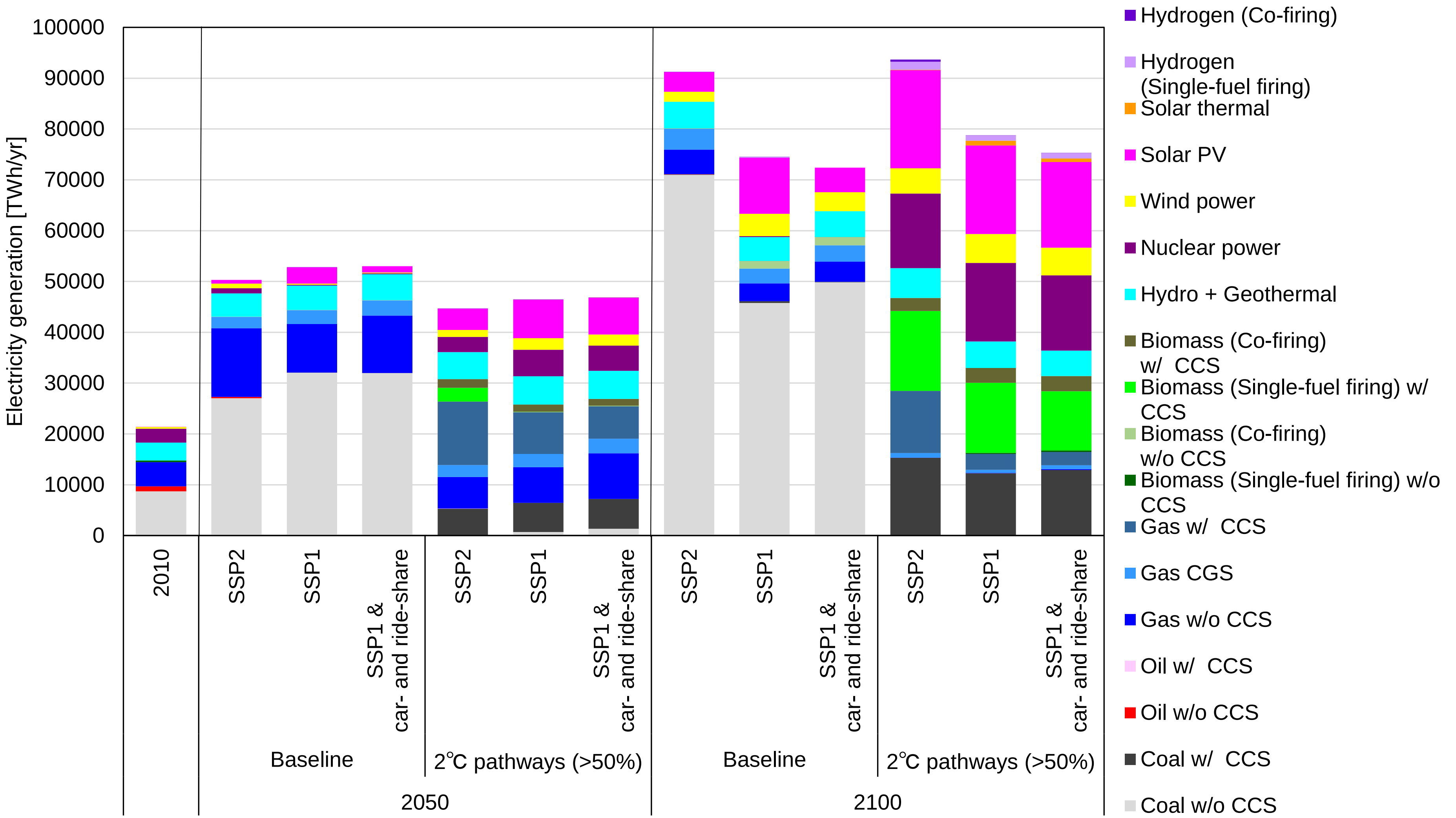

- Global crude steel production is expected to be increased from 2010 to 2050 in all scenarios. On the other hand, the crude steel production of SSP1 and SSP1 & car- and ride-share in 2100 will be considerably smaller than that of SSP2.
- Automotive steel sheet demand is estimated to be decreased due to car- and ride- share. However, that amount is not so much large compared to the total crude steel production.

# Global ethylene and propylene production by technology




**- In all scenarios, ethane crackers are evaluated to dominate over naphtha crackers for the long run.**
**- In the SSP1 & car- and ride-share, ethylene and propylene production slightly drops than the SSP1 due to car- and ride-share.**

# Global electricity generation mix




**- Large decline in $CO_2$ emission in transportation sector occur in SSP1 & car- and ride-share with lower marginal abatement cost, so this induce lower emission reduction levels required for other sectors to achieve -40% compared with 2010, as well as a small amount of introduction of coal power plants without CCS which cannot be allowed under stringent emission reductions.**

# 5. Conclusions and challenges for the future

# Outline of IPCC WG3 AR6 (Co-vice chair: Diana Urge-Vorsatz)

RITE Research Institute of Innovative Technology for the Earth



Framing (1 chapter)

**1. Introduction and framing**

High-level assessment of emission trends, drivers and pathways (3 chapters)

**2. Emissions trends and drivers**
**3. Mitigation pathways compatible with long-term goals**
**4. Mitigation and development pathways in the near- to mid-term**

Sectoral chapters (8 chapters)

**5: Demand, services and social aspects of mitigation**
**6: Energy systems** — **9. Buildings**
**7. Agriculture, Forestry, and Other Land Uses** — **10. Transport**
**8. Urban systems and other settlements** — **11. Industry**
**12. Cross sectoral perspectives**

"New" chapter of AR6

Institutional drivers (2 chapters)

**13. National and sub-national policies and institutions**
**14. International cooperation**

Financial and technological drivers (2 chapters)

**15. Investment and finance**
**16. Innovation, technology development and transfer**

Synthesis (1 chapter)

**17. Accelerating the transition in the context of sustainable development**

## Chapter 5: Demand, services and social aspects of mitigation

- Mitigation, sustainable development and the SDGs (human needs, access to **services**, and affordability)
- *Patterns of development* and **indicators of wellbeing**
- *Sustainable consumption and production*
- Culture, social norms, practices and behavioural changes for lower resource requirements
- Sharing economy, collaborative consumption, community energy
- Implications of **information and communication technologies for mitigation** opportunities taking account of social change
- **Circular economy** (maximising material and resource efficiency, closing loops): and insights from life cycle assessment and material flow analysis
- Social acceptability of supply and demand solutions
- Leapfrogging, capacity for change, feasible rates of change and lock-ins
- Identifying actors, their roles and relationships
- Impacts of non-mitigation policies (welfare, housing, land use, employment, etc.)
- Policies facilitating **behavioural and lifestyle change**

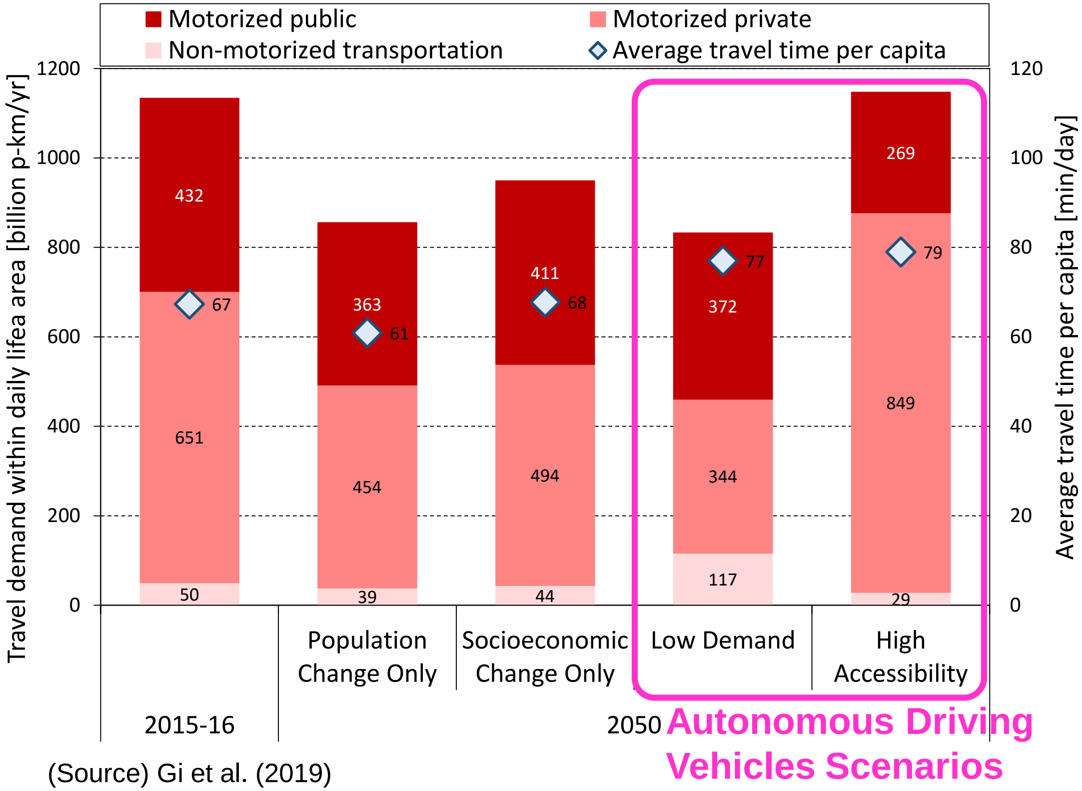
## Chapter 12: cross-sectoral perspectives

- Summary of **sectoral costs and potentials**
- Comparison of sectoral costs and potentials with integrated assessments
- Summary of sectoral **co-benefits and trade-offs**
- Aspects of **GHG removal techniques** not covered in chapters 6 to 11 (land based, ocean based, direct air capture): status, costs, potentials, governance, risks and impacts, co-benefits, trade-offs and spill-over effects, and their role within mitigation pathways
- Impacts, risks and opportunities from large-scale land-based mitigation: land, water, food security; use of shared resources; management and governance
- Emissions intensity of **food systems** and mitigation opportunities across the food system (production, supply chain, demand and consumption) including emerging food technologies
- Policies related to food system and food security including food waste and food demand
- Links to adaptation and sustainable development (including co-benefits, synergies and trade-offs)

# Estimation of Passenger Travel Demand in Japan from Time Use Point of View: Consideration of Rebound Effects

- Everything (e.g., society, economy, technology) will change drastically until 2100.
- Existing Integrated Assessment Models use activity (service, goods) scenarios which are mainly based on historical trend.
- On the other hand, a bottom-up way of demand scenario construction, starting from people's daily life behavior from time budget and time use point of view has a potential to capture service demand change including rebound effects induced by socioeconomic and technological changes transparently, comprehensively and consistently.
- We are considering self-consistent low energy demand scenarios by identifying and quantifying service demand from time use and time budget approach.

✓ Contrasting passenger travel demand scenarios in Japan can be considered, i.e., Low Demand (travel distance by motorized private decreases by 47%) and High Accessibility (travel distance by motorized private increases by 30%).




(Source) Gi et al. (2019)

# Conclusions



- **The total risk management is important understanding several kinds of related uncertainties. We should consider the role of each climate change response measure understanding its costs and potentials. Energy supply side technologies with low- and zero-emissions are surely important.**
- **On the other hand, innovations will be achieved through “new connections” of a number of technologies etc. Technologies not directly related to global warming mitigation will form “new connections”, induce social change, and then help achieve deep $CO_2$ emission reductions. Big progresses in AI, IoT, big data etc. will reduce energy demands without decrease in welfare. (It is important not to directly aim at too much energy saving and global warming mitigation but to endeavor for the innovations of products and services.)**
- **This study conveyed a preliminary analysis of impacts of car- & ride-sharing induced by fully autonomous cars on energy supply and demands and $CO_2$ emission reductions also considering the induced effects on other sectors.**
- **Progresses of AI etc. may bring low energy demands across many sectors but most of current integrated assessment models (IAMs) have not treated them explicitly and quantitatively. Appropriate treatment of innovations in end-use sectors, and consistent analyses including rebound effects are very important scientific agenda for modelers. RITE would like to develop a better IAM treating these innovations and to evaluate the scenarios in collaboration with IIASA and other institutes and researchers.**

# Appendix

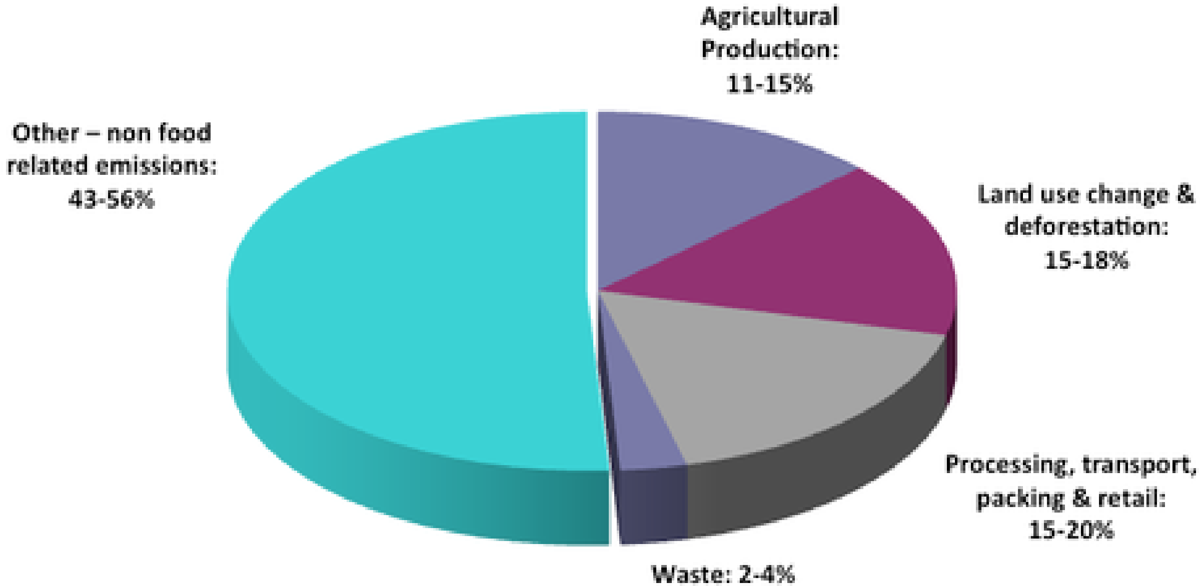
# Energy consumption and GHG emissions throughout food lifecycle

## Energy consumption; an example of the estimations for U.S.


- **10.8 EJ/yr in 1990s: it accounts for approx. 12% of the total energy consumption**

Source：https://www.oregon.gov/deq/FilterDocs/PEF-FoodTransportation-FullReport.pdf

## GHG emissions; an example of the estimations for the world




Source：GRAIN (2011) Food and climate change: the forgotten link

**Energy consumption and GHG emissions in food lifecycle is substantial. If we can reduce food loss, i.e. unfruitful food production, a great ripple effect is expected, since it can contribute to reduce not only direct energy consumption in food processing, transportation and retails but also indirect energy consumption embodied on related products and activities.**

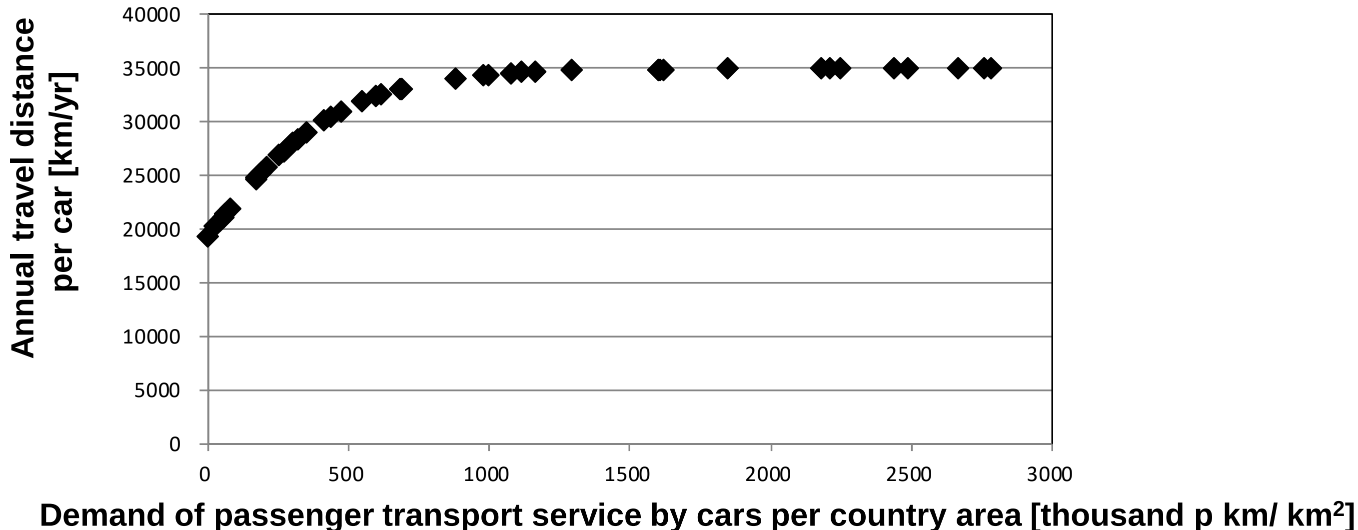
# Major assumptions of car- and ride-sharing



**[Major assumptions] (mainly following Fulton et al. (2017))**

- **Fully autonomous car can be realized in 2030**
- **Additional costs for fully autonomous cars:**
  **+10,000$ in 2030, +5,000$ in 2050, +2,800$ in 2100**
- **Operation ratio of cars: depending on travel service demands of cars per area**
- **Life times of cars: 13-20 years for conventional cars, 6-20 years for share cars**
- **Number of riding per car:**
  **1.1-1.5 people in 2050 and 1.1-1.3 people in 2100 for conventional cars**
  **1.75 people in 2050 and 2 people in 2100 for shared cars**

**A relationship between 'demand of passenger transport service by cars per country area' and 'annual travel distance per car'**



# Major assumptions of car- and ride-sharing and the estimated impacts



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  1.75 people in 2050 and 2 people in 2100 for shared cars

**[Estimated impacts]**

- Number of shared car owned in 2050: 60% compared to that of conventional car owned
- Number of shared car sales in 2050: 70% compared to that of conventional car sales

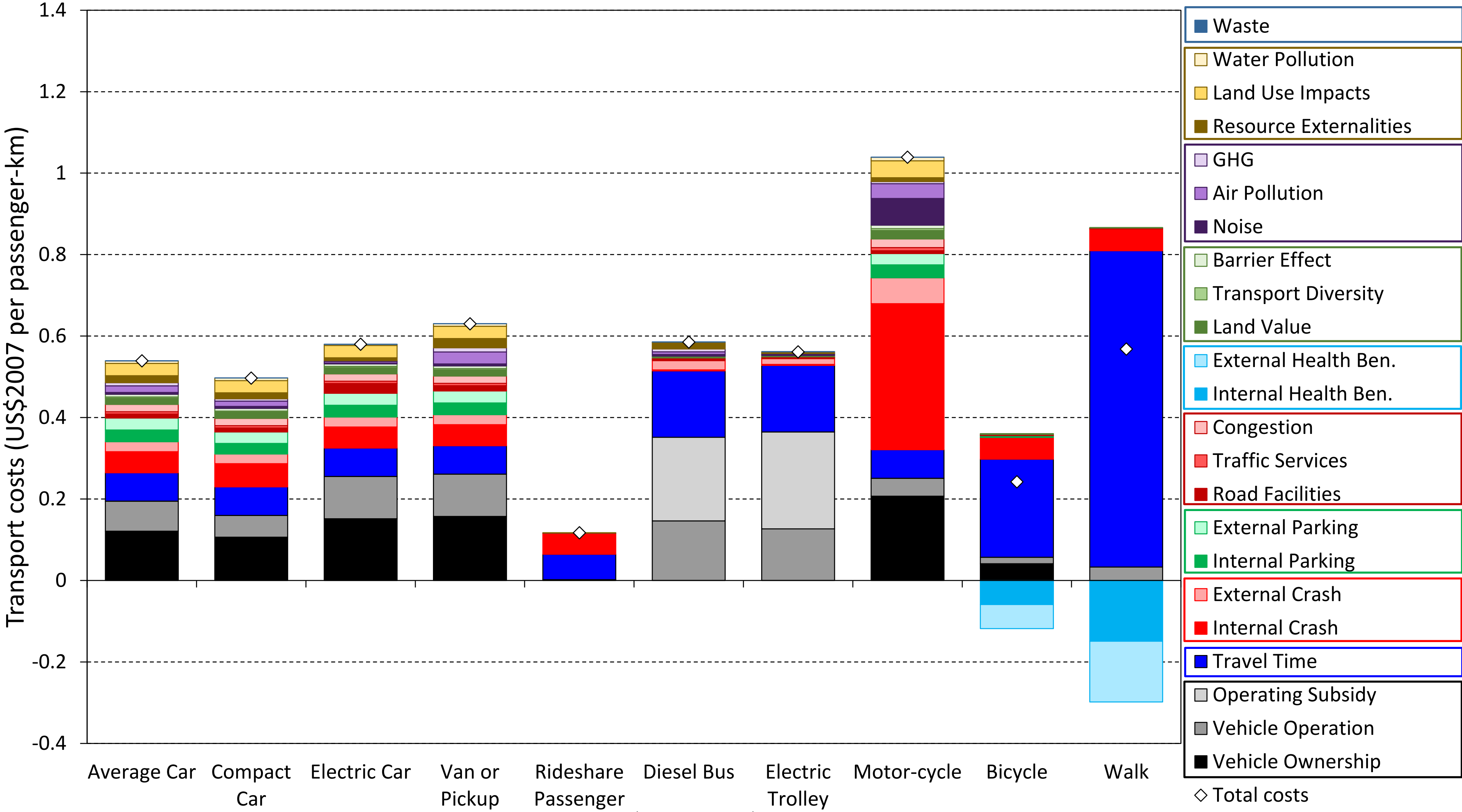
**[Impacts on iron and steel productions]**

- Ton of steel for shred cars: 78% compared to that for conventional cars
- Total iron and steal productions in the SSP1 and car- & ride-sharing scenario: 98% of those in the SSP1 without consideration in car- & ride-sharing

**[Impacts on productions of ethylene and propylene]**

- Share of productions of ethylene and propylene in productions of plastics:85%
- The share for cars in the productions of ethylene and propylene: 8%
- Total productions of ethylene and propylene: 99% (accordingly reductions in naphtha and ethane)

# Average Transport Costs per Passenger-km by mode




（Data Source） Litman, Transportation Cost and Benefit Analysis (2009, 2015, 2017, 2018)

**▪Costs other than vehicle costs account for large fraction.**

**▪We have included travel time and safety costs to DNE21+ at first to consider opportunity benefits/costs of autonomous driving vehicles and car-sharing.**

# Assumptions on Opportunity Benefits/Costs for Autonomous Driving Vehicles and Car-Sharing*



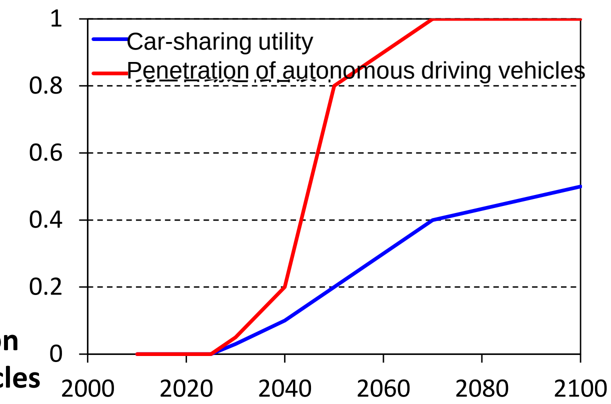
| | Travel Time | Safety |
|---|---|---|
| **Autonomous Driving Vehicles Only** | Wage ($/hour) = Per capita GDP ($/year) ÷ *2000* (hour/year; Annual working time)<br>Travel time (hour/year) = Travel distance (p-km/year) ÷ *30* (v-km/hour; Travel speed)<br>**Driving Free benefit** ($/year) = Wage ($/hour) × *0.15* (Benefit rate) × Travel time | **Safety Improvement benefit** ($/year) = *0.1* ($/v-km) × (1 – Rate of penetration of autonomous driving vehicles) × Travel distance (v-km/year) |
| **Car-Sharing Only** | **Car-Sharing cost** ($/year) = Wage × *0.35* (Cost rate) × Travel time × *0.1* (Increase rate of total travel time) × (1 – Car-Sharing utility) | |
| **Autonomous Driving Vehicles and Car-Sharing** | **Driving Free benefit** ($/year)<br>**Car-Sharing cost** ($/year) | **Safety Improvement benefit** ($/year) |

***Relative benefits/costs compared with conventional auto-mobiles**

Assume two type of benefits/costs

・**Travel Time Benefit/Cost**: Driving Free benefit and Car-Sharing cost

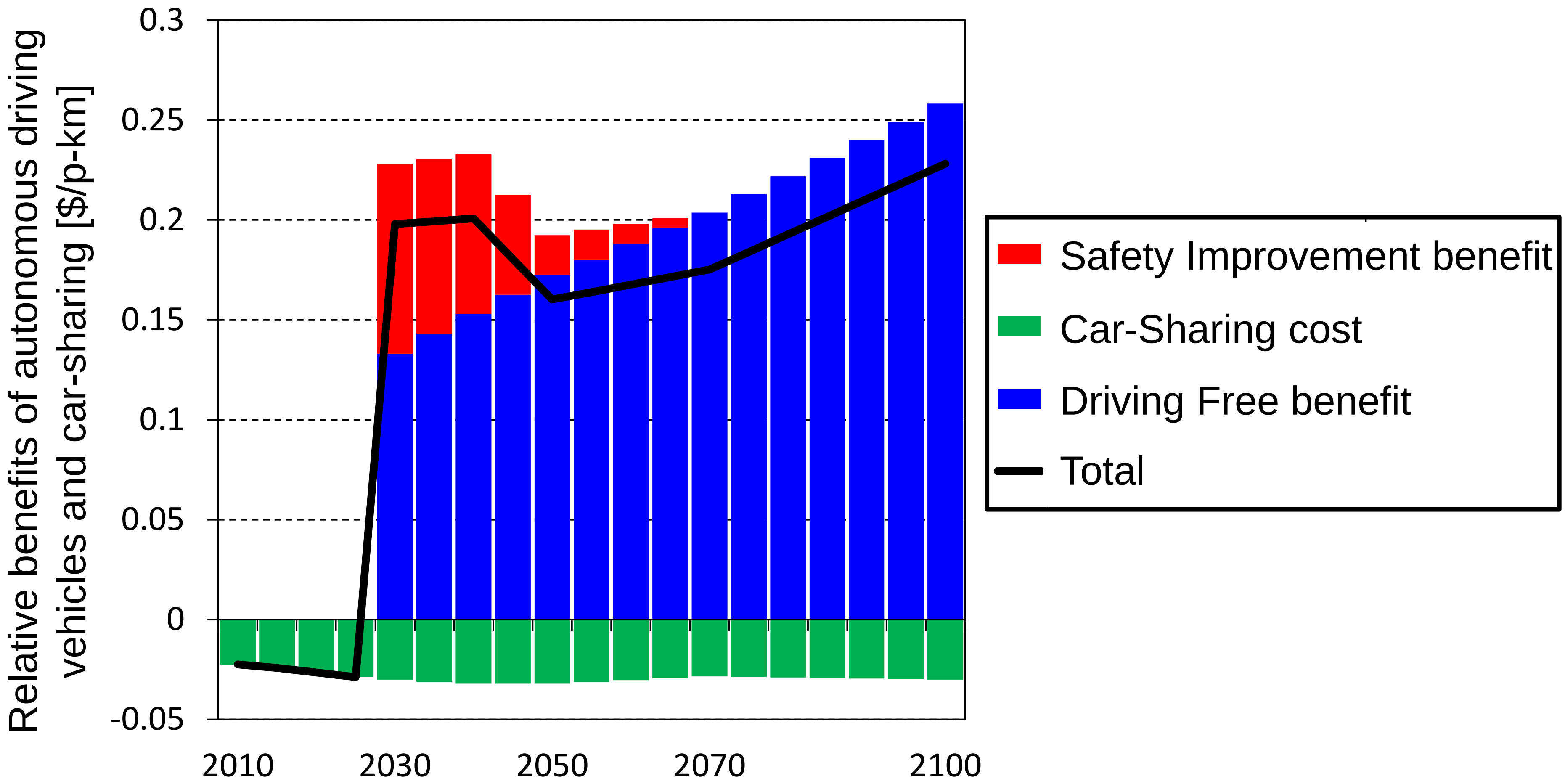
・**Safety Improvement Benefit**




**Assumptions on car-sharing utility and rate of penetration of autonomous driving vehicles**

# An example of estimation of opportunity benefits/costs by autonomous driving vehicles and car-sharing: the United States






- **Driving Free Benefit** increases gradually due to increase of wage
- **Car-Sharing cost** saturates because the increase of car-sharing caused by increase of wage is cancelled by increase of the utility of car-sharing.
- **Safety Improvement benefit** is initially high but decreases rapidly due to penetration of autonomous driving vehicles.

# The estimated impacts of car- and ride-sharing on number of owned car and the other sectors



## [Estimated impacts]

- Number of shared car owned in 2050: 60% compared to that of conventional car owned
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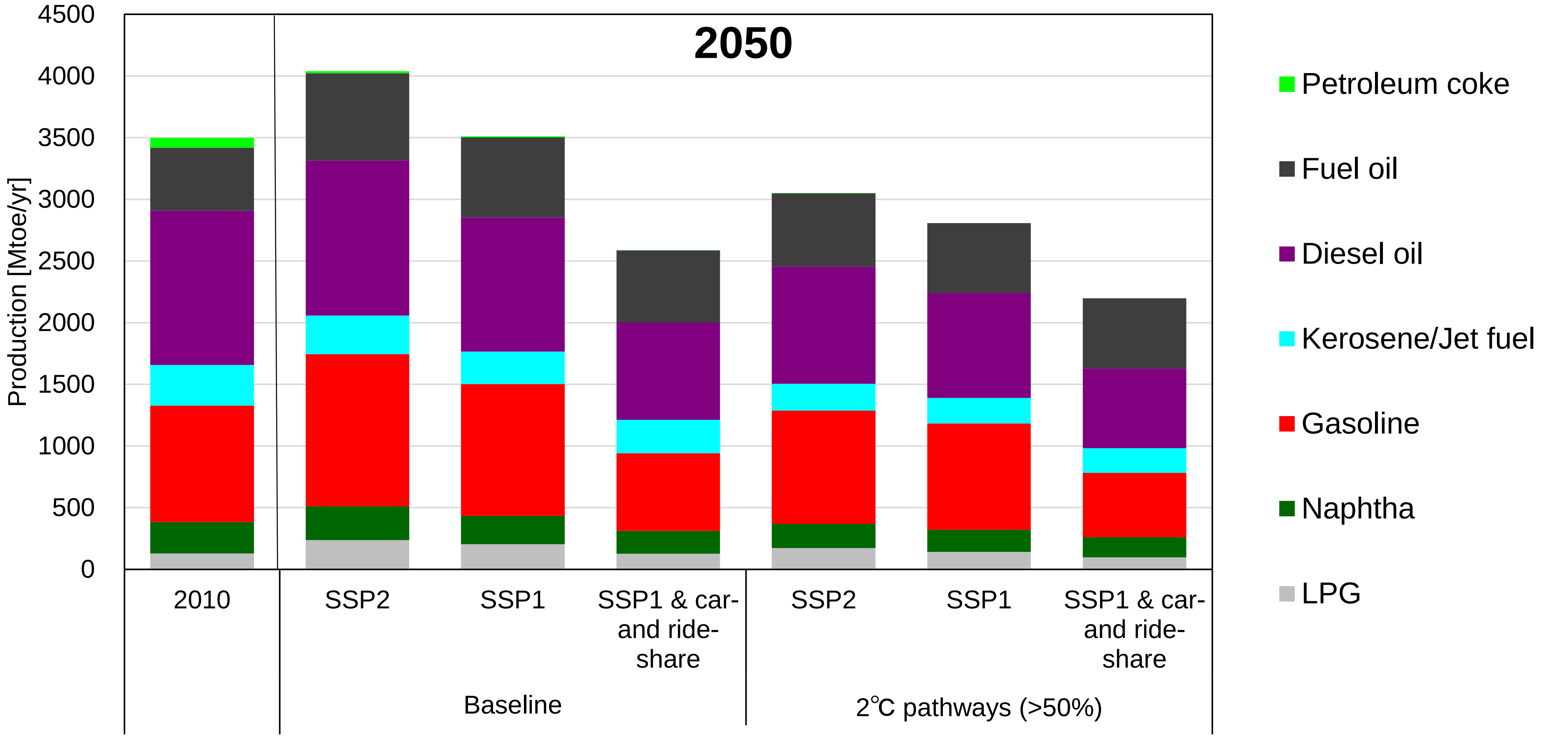
# Global oil refinery by product

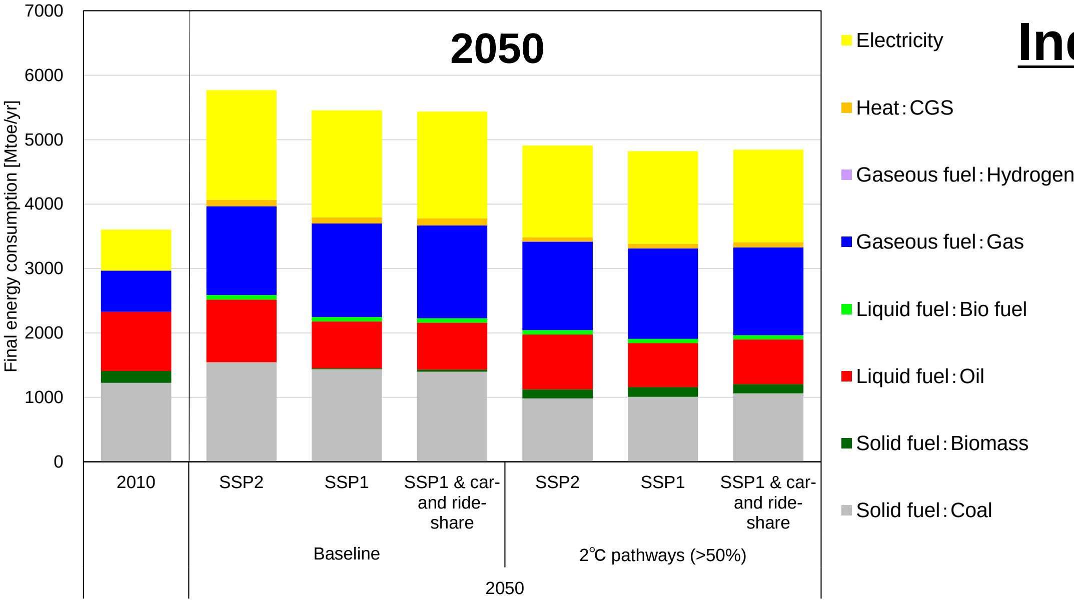




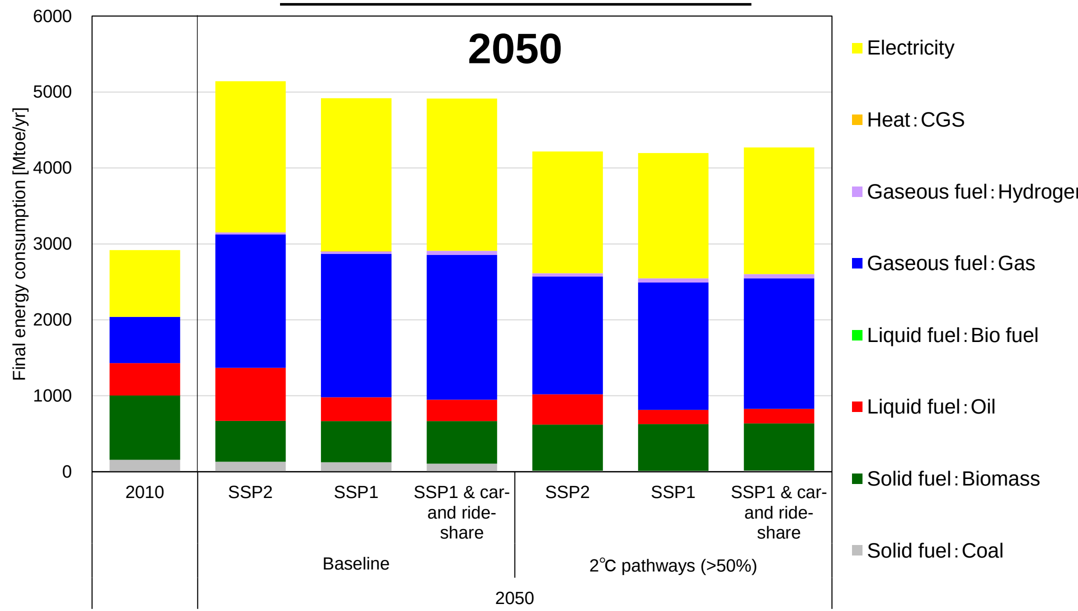

**- Gasoline and diesel oil for automobiles are reduced in SSP1, and SSP1 & car- and ride-share compared to SSP2. (SSP2⇒SSP1, SSP1 & car- and ride-share)**

# Global final energy consumption by sector

## Industrial sector



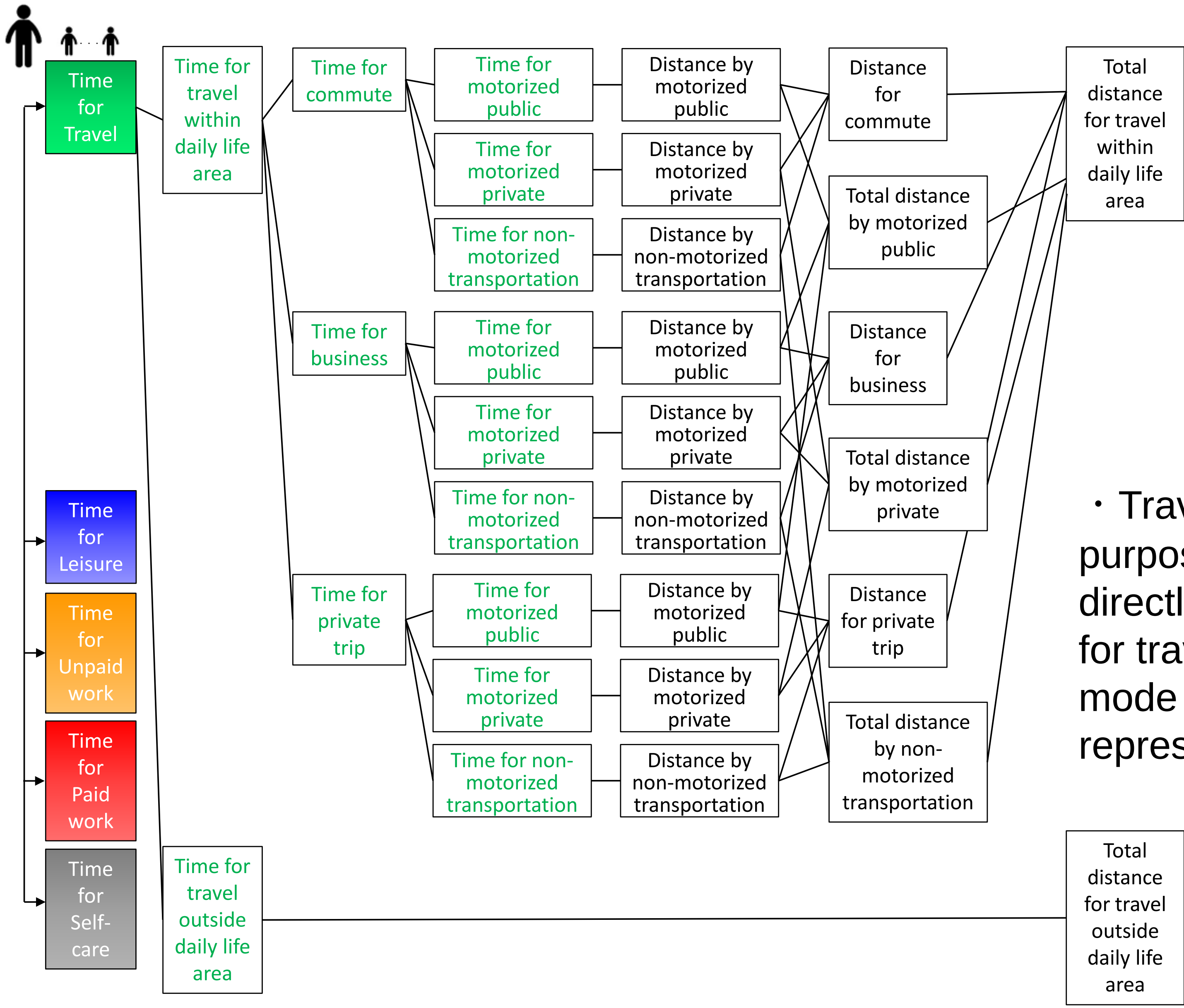

## Residential and commercial sector




**- Gas and electricity demand in the industrial sector and residential and commercial sector is expected to be increased in 2010 through 2050 in all scenarios.**

**- As shown in the global ethylene and propylene production, fuel switching from oil to gas is occurred for achieving $CO_2$ emission reduction. But as a whole, gas demand in the 2℃ pathways is smaller than that in the baseline.**

# Framework for assessment of passenger travel demand




・Travel distance by purpose and mode is directly connected to time for travel by purpose and mode for each representative actor.

# Representatives and Procedure for Bottom-up Estimation of Passenger Travel Demand

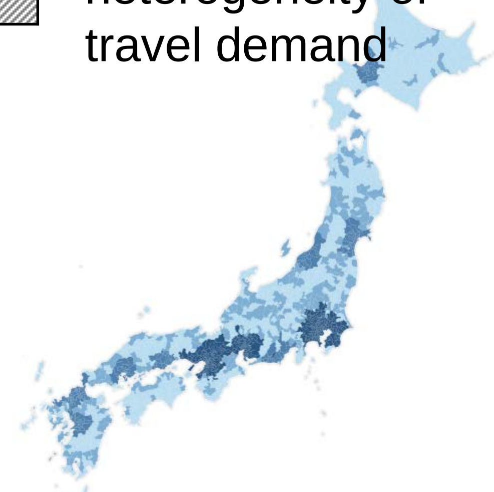
| Sex | Age | Employment | Representative |
|---|---|---|---|
| Male | 15-29 | Working | M1 |
| | | Non-working | M2 |
| | 30-49 | Working | M3 |
| | | Non-working | M4 |
| | 50-64 | Working | M5 |
| | | Non-working | M6 |
| | 65+ | Working | M7 |
| | | Non-working | M8 |
| Female | 15-29 | Working | F1 |
| | | Non-working | F2 |
| | 30-49 | Working | F3 |
| | | Non-working | F4 |
| | 50-64 | Working | F5 |
| | | Non-working | F6 |
| | 65+ | Working | F7 |
| | | Non-working | F8 |

| Occupation | Representative |
|---|---|
| Administrative, managerial | A |
| Professional, technical, clerical, sales, service, security | B |
| Agricultural, forestry, fishery | C |
| Manufacturing process | D |

×

| Region | Representative |
|---|---|
| Three metropolitan areas | M |
| Major cities | U |
| Cities | C |
| Villages | V |

・Set 160 representatives to simulate personal heterogeneity of travel demand



**Total travel demand** $_{Japan}$ (p-km/yr) = **Total travel demand within daily life area** $_{Japan}$ (p-km/yr) + **Total travel demand outside daily life area** $_{Japan}$ (p-km/yr)

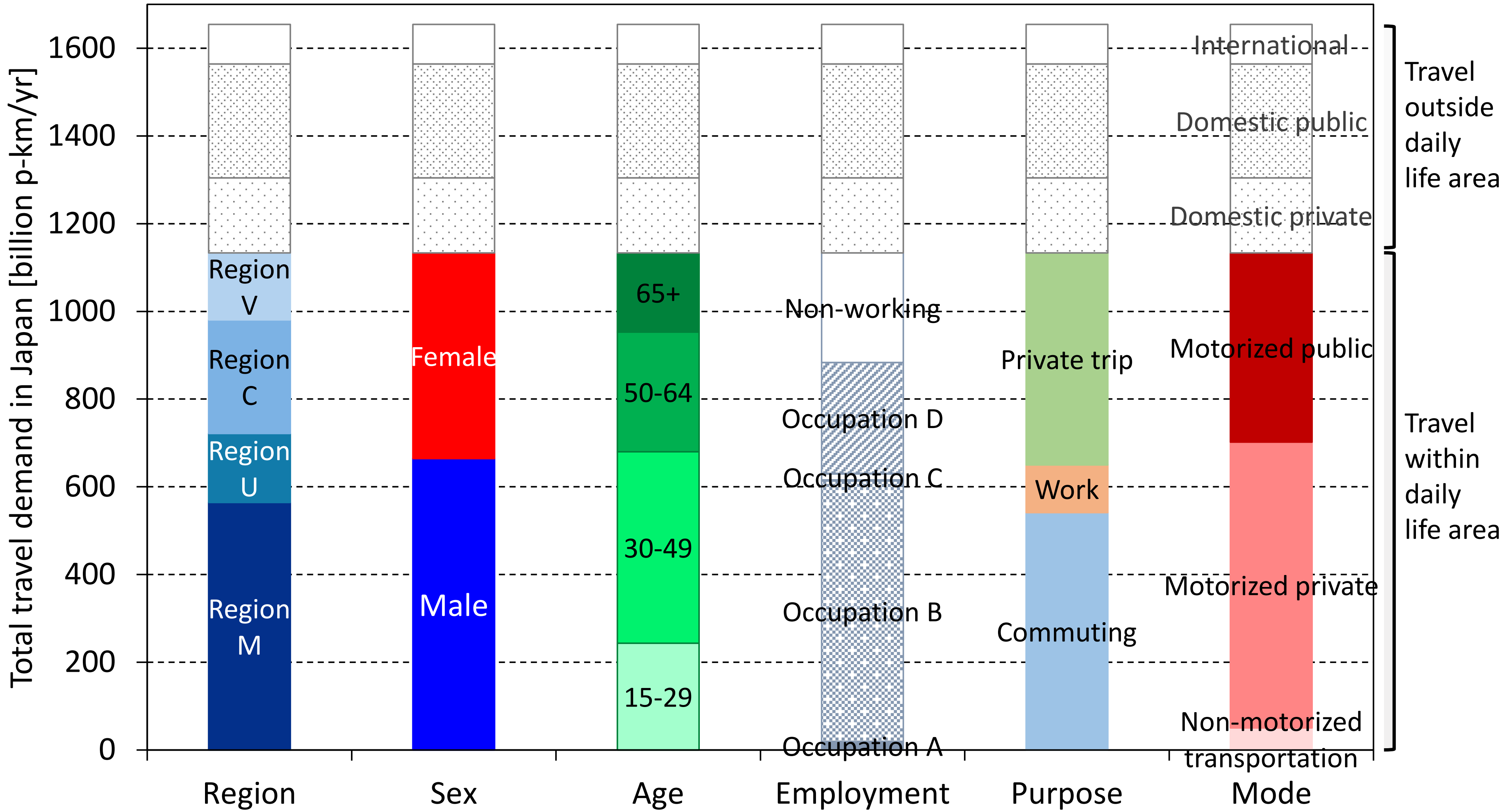
**Travel demand within daily life area** $_{R, P, M}$ (km/yr)
= **Trip rate** $_{R, P, M}$ (trip/yr) × **Trip distance** $_{R, P, M}$ (km/trip)
= **Trip rate** $_{R, P, M}$ (trip/yr) × **Trip time** $_{R, P, M}$ (h/trip) × **Travel speed** $_{R,M}$ (km/h)
= **Travel time** $_{R, P, M}$ (h/yr) × **Travel speed** $_{R,M}$ (km/h)

R: personal attributes (region, sex, age, employment, occupation), P: trip purpose (commuting, work, private trip), M: travel mode (non-motorized transportation, motorized private, motorized public)

# Total passenger travel demand in 2015-16 in Japan



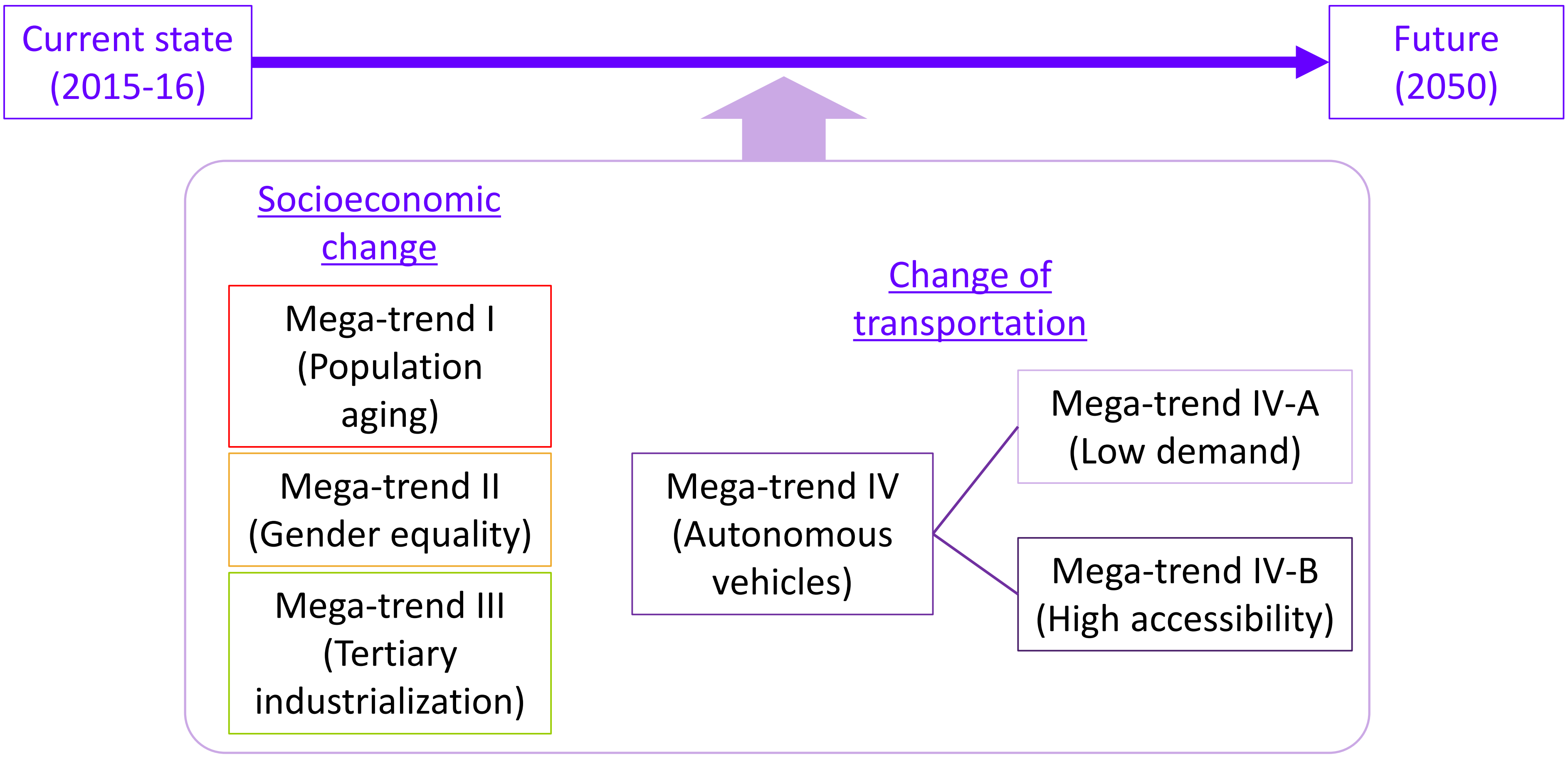
* **Non-motorized transportation**: walk, bicycle, etc., **Motorized private**: private cars, motorcycles, etc., **Motorized public**: buses, railways, etc.




・Energy consumption for passenger travel can be calculated by using energy systems models based on passenger travel demand by mode.

# Passenger travel demand scenarios in Japan






・We consider mega-trends in terms of socioeconomic change (Mega-trend I-III) and transportation technology innovation (Mega-trend IV).

# A narrative of four mega-trends in Japan for future mobility demand scenarios



| Mega-trend | | | Storyline |
|---|---|---|---|
| I Population Aging | | a | Change of population structure by region, sex and age. |
| | | b | Increase of employment rate for people those aged 65 and over. |
| II Gender Equality | | a | Increase of employment rate and administrative positions for women. |
| | | b | Convergence of gender difference of trip purpose by mode. |
| III Economic Growth (Tertiary Industrialization) | | | Shift from blue-collar workers to white-collar workers. |
| IV Transport Technology Innovation | Common | a | Increase of preference for motorized private due to distribution of autonomous driving vehicles. |
| | | b | Increase of travel speed by motorized private thanks to efficiency improvement of traffic flow by distribution of autonomous driving vehicles. |
| | A Low Demand | a | Decrease of effective travel speed by motorized private because of waiting time for sharing vehicles. |
| | | b | Decrease of private trip demand due to increase of utility of online shopping and leisure at home. |
| | | c | Decrease of commuting trip demand by employed people due to increase of teleworking for white-collar workers. |
| | | d | Decrease of commuting trip demand by students due to e-Education. |
| | | e | Increase of trip demand by non-motorized transportation in cities for health improvement. |
| | | f | Increase of trip demand by motorized public and decrease of trip distance in cities thanks to compact urban design. |
| | B High Accessibility | a | Increase of private vehicles ownership because of increase of preference for on-demand trips and shift from trips by motorized public to those by motorized private. |
| | | b | Increase of travel speed thanks to intelligent transport systems. On the other hand, travel speed by motorized private decreases in cities center because of traffic congestion caused by increase of private vehicles. |
| | | c | Expansion of the urban area thanks to the improvement of utility of motorized private and motorized public on the move. |
| | | d | Shift of access/egress traffic from non-motorized transportation to motorized private. |