NEDO
PV-Powered Vehicle Strategy Committee
Interim Report

January 2018

New Energy and Industrial Technology Development Organization

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Interim Report of PV-Powered Vehicle Strategy Committee: Table of Contents

Introduction

The Paris Agreement adopted at COP21 came into force through successive ratification by the United States, China, the EU, and Japan, and marked a new step forward as an international framework for counteracting global warming following the Kyoto Protocol.

It became clear, however, that even if the 165 Intended Nationally Determined Contributions (INDCs) submitted by the signatory countries are achieved, it will still be extremely difficult to realize a scenario in which the Paris Agreement goal of keeping the rise in average global temperature to within 2°C is achieved. Individual countries therefore need to set more ambitious targets for reducing greenhouse gases.

At present, greenhouse gas emissions are falling in the power generation sector due to the accelerated introduction of renewable energy such as photovoltaics (PV) and wind. In the transport sector, however, which relies on fossil fuel for most of its energy needs, a presently unforeseeable level of innovative technology development will be essential to outperform the current greenhouse gas reduction targets. In particular, the number of automobiles, which account for the majority of transport emissions, is forecast to grow rapidly mainly in Asia, and reducing their greenhouse gas emissions with cutting-edge technology will be an important factor in determining whether the Paris Agreement target of 2°C is achieved.

Although increasingly tougher regulations on automobile exhaust emissions, especially in Europe and the US, have spurred the sale and introduction of electric vehicles (EVs) and plug-in hybrid vehicles (PHVs), unless clean energy derived from renewable sources can be supplied from the grid, such vehicles will have a limited effect in reducing greenhouse gas emissions.

In 2016, a NEDO research and development project achieved a conversion efficiency of 31% at PV module level, and in overseas, the Solar Impulse aircraft achieved a circumnavigation of the earth using only solar power. These technologies demonstrated the potential of PV as an important energy source in mobility applications where installation area is limited.

Based on these developments, the National Energy and Industrial Technology Development Organization (NEDO) established a PV-Powered Vehicle Strategy Committee and investigated the potential for contributing to reducing CO_2 emissions in the transport sector by installing high-efficiency PV cells on automobiles. Mizuho Information & Research Institute, Inc. (MHIR) served as the Secretariat to the Committee. This report summarizes the interim results of this study by the PV-Powered Vehicle Strategy Committee.

1. Significance and Role of PV-Powered Vehicles in Low-Carbon Society

PV cells with very high conversion efficiency show promise as a power source for equipment in applications where there are severe restrictions on installation area. One potential application where installation area is limited is a PV-powered vehicle, produced by mounting PV cells on a next generation vehicle, such as an electric vehicle.

In this study, the possible significance of PV-powered vehicles in future society was investigated.

1.1. Global Trends in Reducing Greenhouse Gas Emissions

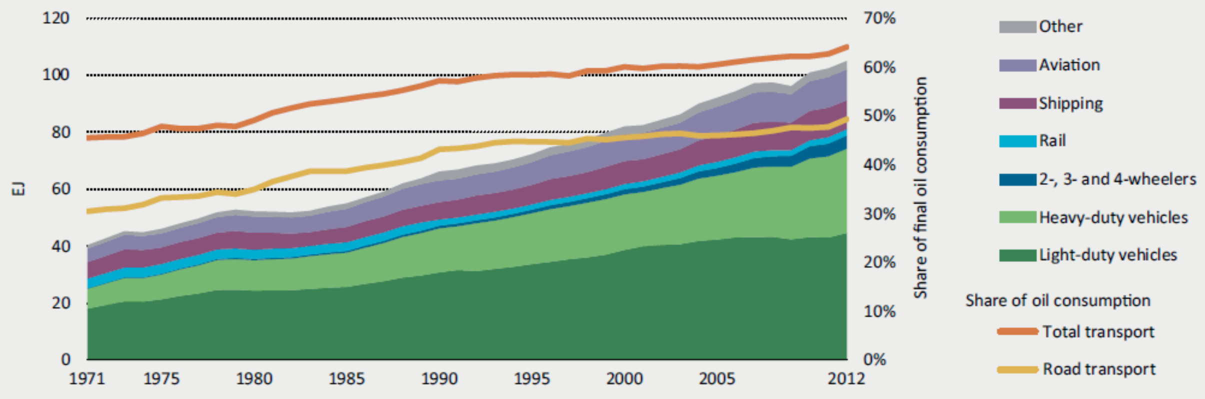
As shown in Table 1-1, every country at COP21 has set aggressive greenhouse gas emission reduction targets, and, at the global level, a sharper fall in greenhouse gas emissions is expected.

As shown in Fig. 1-1, automobiles (light-duty vehicles and heavy-duty vehicles) are responsible for a large proportion of the energy consumption in the global transport sector. Such energy use has increased further in recent years, and is one factor in the increase in greenhouse gas emissions.

Fig. 1-2 shows the required reductions in greenhouse gas emissions by sector in 2DS (i.e., the scenario for suppressing temperature rise to 2 degrees) indicated by the IEA. For the transport sector, a reduction contribution of 20% across the entire sector is expected by 2050 as the required reduction.

Table 1-1 Greenhouse gas emission reduction targets in INDCs of main signatory countries[1]

Country	Reduction target		
	Target value	Target year	Reduction
China	GDP-based	By 2030 based on 2005 levels	60% to 65%
USA	Total	By 2025 based on 2005 levels	26% to 28%
EU	Total	By 2030 based on 1990 levels	At least 40%
India	GDP-based	By 2030 based on 2005 levels	33% to 35%
Russia	Total	By 2030 based on 1990 levels	25% to 30%
Japan	Total	By 2030 based on 2013 levels	26%



Notes: Light-duty vehicles are cars and light trucks (up to 3.5 tonnes); heavy-duty vehicles are trucks and buses. Aviation and shipping include international bunkers, i.e. fuels used for international aviation and navigation.

Fig. 1-1 Global transport energy consumption by mode[2]

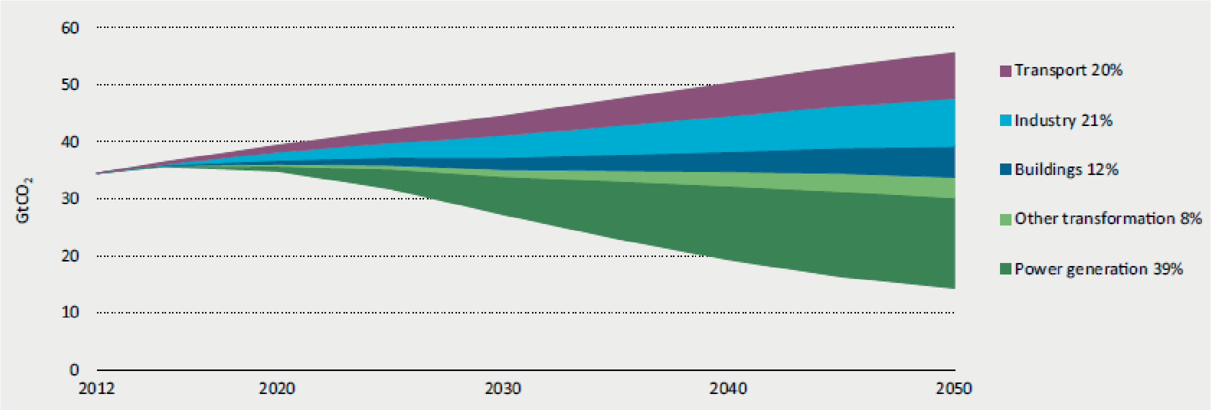
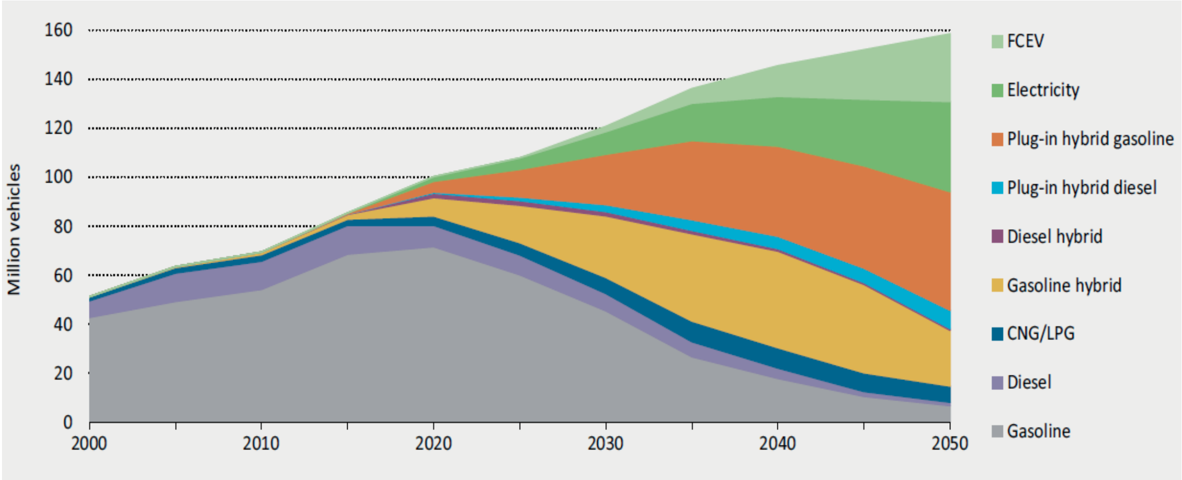


Fig. 1-2 Global CO$_2$ reductions between 6DS and 2DS by sector[2]

1.2. Reducing the Impact on Power Grids due to Widespread Use of Next Generation Vehicles

As shown in Fig. 1-3, to reduce greenhouse gas emissions in the transport sector, next generation vehicles, in the form of electric vehicles (EVs), plug-in hybrid vehicles (PHVs), hybrid vehicles (HEVs) and fuel cell vehicles (FCEVs), are expected to become widespread. In the IEA 2DS, it is assumed that in 2050, about 80% of new car sales will be PHVs, EVs and FCEVs.

As these next generation vehicles become common in the future, an increase in demand for electricity in the transport sector is forecast. It is believed that next generation vehicles will have a large impact on power grids, such as increasing power source requirement and pressure on grid capacity. If PV-powered vehicles became feasible, it would be possible to supply power to vehicles on-site without relying on the grid, thereby reducing the impact of next generation vehicles on power grids.



Note: CNG = compressed natural gas; LPG = liquefied petroleum gas.

Fig. 1-3 Global portfolio of technologies for PLDVs (passenger light-duty vehicles) in the 2DS[2]

1.3. Expanding the Market for High-Efficiency PV Cell Technology

Technology development into PV cells in Japan is directed at achieving ever higher efficiencies for PV cells to reduce the cost of power generation, and has already developed PV cells with world-leading high-efficiency. However, in the actual market, high-efficiency PV cells are currently used only in limited applications, and future market expansion remains a challenge. If the price of high-efficiency PV cells could be brought down further by market expansion to spur their introduction into wider applications, this would result in a large reduction in the environmental burden of society.

Since high-efficiency PV cells generate more power using a smaller area, they are competitive in applications where the installation area is restricted. One promising market is installation on next generation vehicles.

Module by Sharp Corporation
Conversion efficiency: 31.17%
(968 cm^2)

Module by Kaneka Corporation
Conversion efficiency: 24.37%
(13,177 cm^2)

Fig. 1-4 Examples of PV modules using high-efficiency PV cells

1.4. Significance of Introduction of PV-Powered Vehicles

As described in Sections 1.2 and 1.3, PV-powered vehicles have a potential as a technology that will increase the added value and expand the market in the PV industry, especially for high-efficiency PV cells, and in the next generation automobile industry, reduce the impact on the grid, thereby further increasing the added value.

If both industries can succeed in realizing and spreading PV-powered vehicles through their initiatives, a significant contribution to reducing greenhouse gas emissions in the global transport sector is expected.

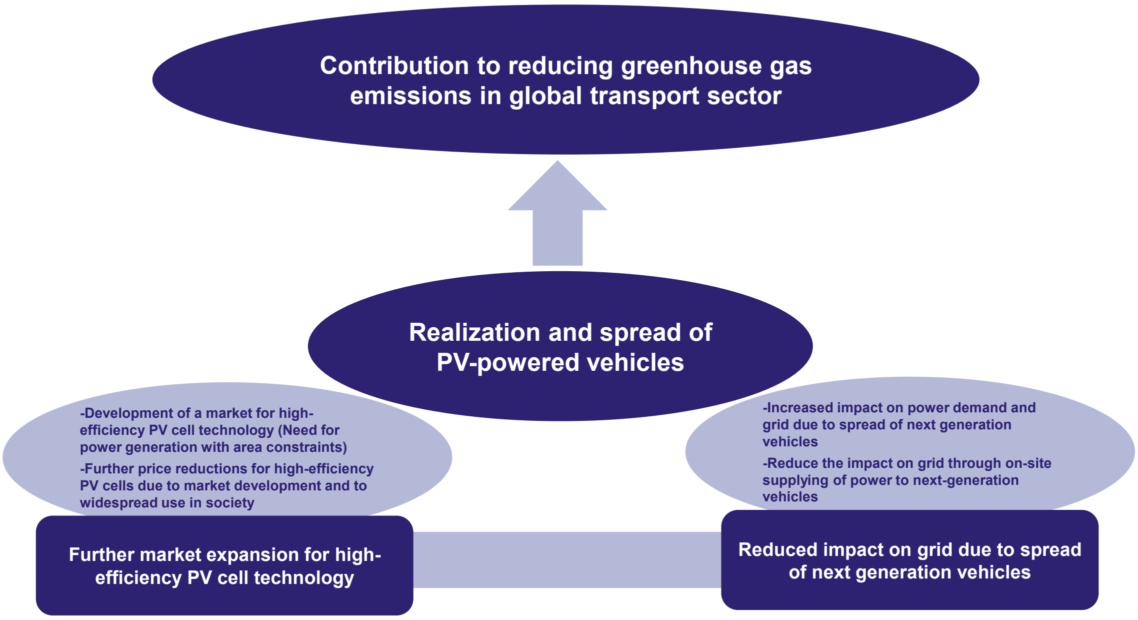


Fig. 1-5 Significance of introduction of PV-powered vehicles

2. Investigation of Added Value of PV-Powered Vehicles

The added value of PV-powered vehicles was analyzed from the viewpoints of reduction in CO_2 emissions, economic benefit, and improvement of convenience. The reduction potential in CO_2 emissions by society as a whole due to the spread of PV-powered vehicles was also estimated.

2.1. Concept of Added Value per PV-Powered Vehicle

2.1.1. Calculation of Added Value

i. Setting Baseline and Evaluation Model

In this study, CO_2 emissions during driving were compared for an EV (the “EV case”) and an EV that is based on the same vehicle but is equipped with an onboard PV system (the “EV + onboard PV case”). In this comparison, as shown in Fig. 2-1, only the effect of providing the PV system was evaluated without considering the CO_2 emissions caused by the manufacturing and disposal of the base vehicle.

In the same way, when assessing a society-wide reduction in CO_2 emissions, the society-wide reduction in CO_2 emissions for a case where PV systems are installed on next generation vehicles was quantified with the presently forecast number of next generation vehicles to be introduced kept constant, with the case where onboard PV systems (onboard PV) are not installed as a baseline.

In this study, next generation vehicles includes three types: HEVs, PHVs and EVs. For PV systems installed on HEVs, it was assumed that generated power replaces gasoline consumption. Driving distance and driving patterns were assumed to be exactly the same irrespective of whether PV systems were installed.

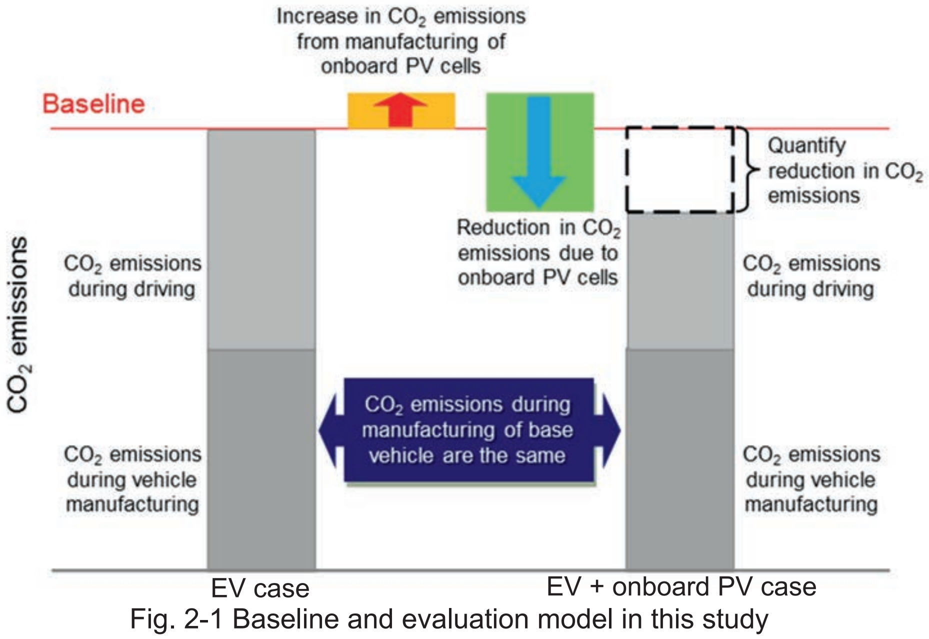


Fig. 2-1 Baseline and evaluation model in this study

ii. Theoretical Basis for Quantification of Added Value

Installing PV systems on the three kinds of next generation vehicles, i.e., HEVs, PHVs and EVs, reduces the power consumption of such vehicles, thereby reducing the amount of power supplied from the grid and fuel consumption. By doing so, it is possible to reduce mostly fossil fuel-derived CO_2 emissions that accompany power generation or the combustion of fuel.

Since the actual added value will differ depending on how the driver use a vehicle and the onboard battery capacity, it will not be possible to always use 100% of the power generated by onboard PV. For example, if a user does not drive the vehicle for several days, power generated by the PV system will gradually charge the battery, and once the battery has no remaining free capacity, any surplus electricity generated thereafter cannot be used.

The amount of power to be stored in an onboard battery is given by the difference between the generated power and the power consumed. When the generated power is greater than the consumed power, the remainder is stored in the onboard battery. However, when the onboard battery has been highly charged and there is little free capacity, it is not possible to charge the onboard battery with the power generated by the PV system, resulting in the creation of surplus power that will be curtailed as shown in Fig. 2-2.

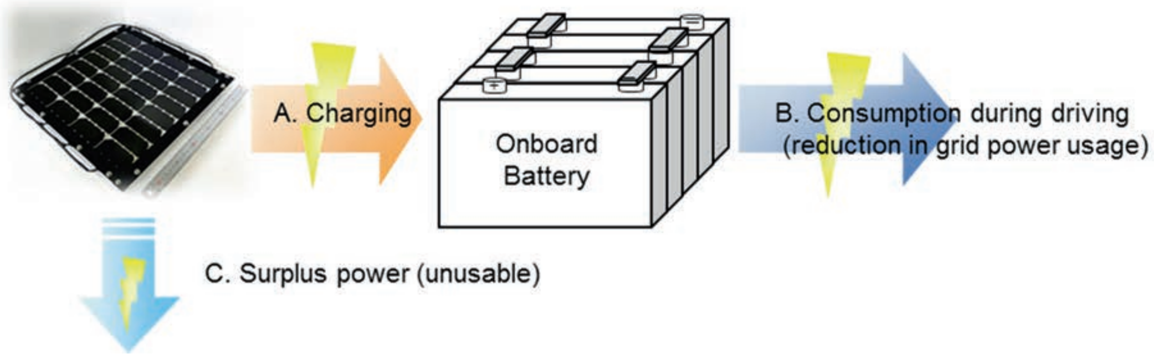


Fig. 2-2 Image of surplus power created due to battery capacity restrictions

During quantification, taking into account the battery constraints described above, as shown in Fig. 2-3, an amount of power given by subtracting unusable surplus power caused by the user's usage pattern and the battery capacity from the actual power generated by onboard PV was referred to the "reduction in grid power usage" achieved through the introduction of onboard PV system. The reduction in CO_2 emissions, the economic benefit to the user, and the reduction in frequency of charging were evaluated based on this reduction in grid power usage.

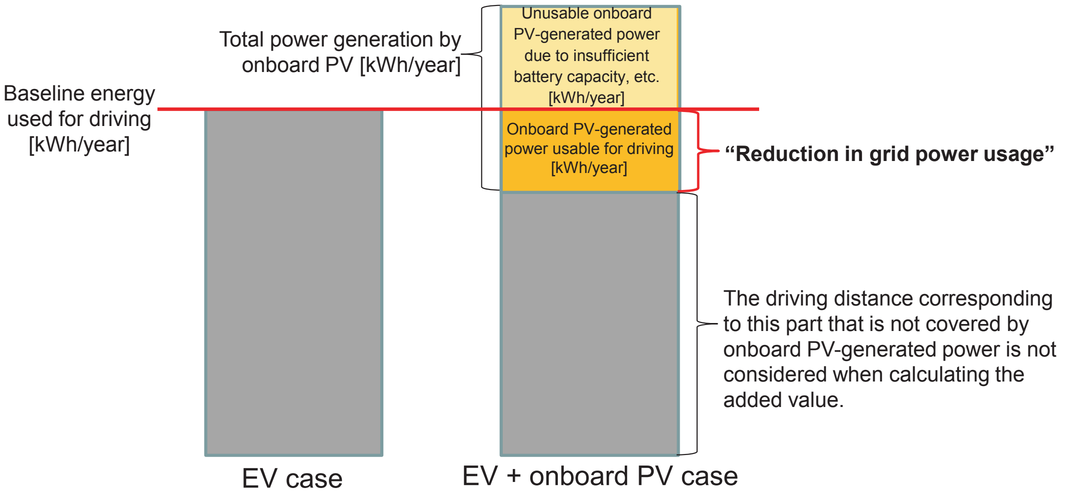


Fig. 2-3 Baseline for evaluating the effect of introducing onboard PV

When comparing an HEV and an HEV with the onboard PV system, instead of the reduction in grid power usage, electric fuel economy defined as the distance that a vehicle can travel per kWh and fuel consumption for gasoline were used to convert the onboard PV-generated power to a reduction in gasoline consumption, and the reduction in CO_2 emissions equivalent to the combustion of this amount of gasoline was calculated. The method of calculating the reduction in grid power usage will be described later in 2.1.3.

Note that although installing onboard PV may actually increase some weight of the vehicle, this study assumes that there is no change in weight or influence on electric fuel economy.

iii. Calculating Reduction in CO_2 Emissions

The reduction in CO_2 emissions was calculated by subtracting the amount of CO_2 emissions generated by adding onboard PV from the product of the reduction in grid power usage and the CO_2 emission factor for grid power.

Regarding the parameters used in this evaluation, the CO_2 emission factor for grid power includes only the emissions related to power generation, and does not include emissions related to the construction and disposal of power stations. Likewise, the emission factor for gasoline includes only CO_2 produced by combustion, and does not include CO_2 emissions during crude oil extraction, gasoline refining, and transportation. On the other hand, for the CO_2 generated by onboard PV, CO_2 emissions generated from manufacturing to disposal of a PV system were considered. In more detail, the life cycle CO_2 emissions of a polycrystalline silicon PV system were used.

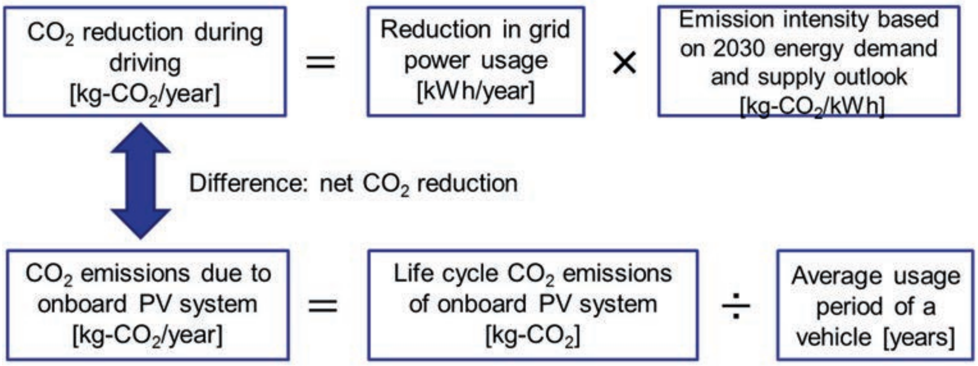


Fig. 2-4 Calculation of net reduction in CO_2 emissions

When calculating the net reduction in CO_2 emissions, the product of the reduction in grid power usage due to power generated by onboard PV and the CO_2 emission factor was used as the reduction in CO_2 emissions during driving, and the difference between this value and the CO_2 generated from the manufacturing to disposal of onboard PV was calculated as the net reduction in CO_2 emissions. Note that although some automobile parts become unnecessary due to the installation of a PV system, and a reduction in CO_2 emissions relating to the manufacturing of such parts is conceivable, it was excluded from the reduction in CO_2 emissions used in this study.

iv. Calculation of Economic Benefit

Installing a PV system on a vehicle reduces the amount of power purchased from a power company. The resulting fall in electricity expenditure is regarded as an economic benefit, and the economic benefit of onboard PV for users was calculated by subtracting the price of onboard PV from the fall in electricity bills.

Owners of PHVs and EVs in general sign a contract to use charging stands installed by providers such as car manufacturers. Even if the number of charging performed at a stand may fall to almost zero once an onboard PV system is installed, it is unlikely that vehicles will become completely charging-free, meaning that some use of charging stands on the go may still occur. Accordingly, such contract fees were not considered for economic benefit from the introduction of onboard PV. Also, since many owners will charge their EV or PHV at home, an ampere-based fixed price component of their electricity bills based on the contract with a power company was not considered for economic benefit. Note that in this study, since all economic benefits were calculated on an annual basis, a discount rate was not applied.

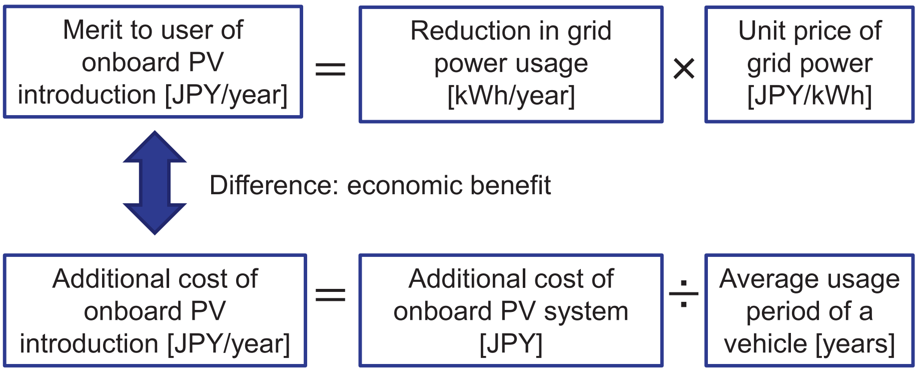


Fig. 2-5 Calculation of economic benefit

2.1.2. Estimating Representative Driving Patterns

Various driving patterns of vehicles are assumed according to the user's place of residence and user attributes. From past research, it is known that traffic volume on roads fluctuates on a yearly or weekly cycle.

In this study, ten driving patterns (C1 to C10) of private passenger cars for a one-week cycle obtained by a previous survey were reclassified to obtain the six driving patterns depicted in Fig. 2-6. Table 2-1 includes details of these six types of driving patterns and user images corresponding to the respective driving patterns.

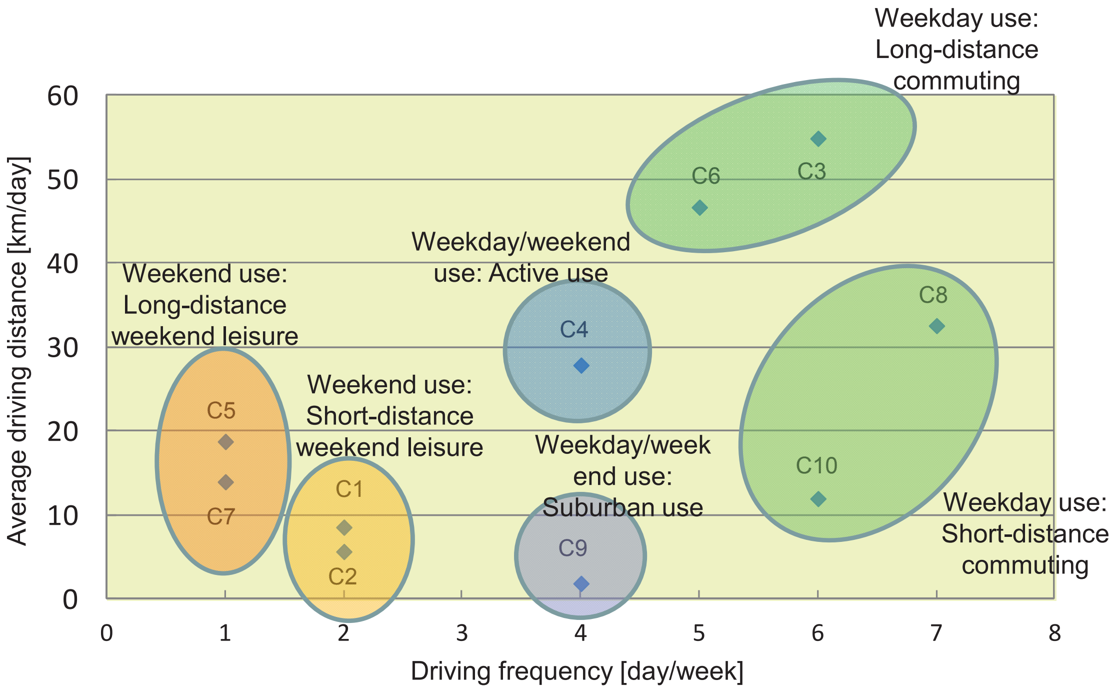


Fig. 2-6 Representative driving patterns

Table 2-1 Representative car usage patterns and user images for evaluating introduction of onboard PV

Pattern	Type	Driving distance per journey (km)	User image
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	Use only on weekends (Sat./Sun.) for visiting distant locations for leisure, etc.
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	Use only on weekends (Sat./Sun.) for visiting nearby locations for leisure, etc.
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	Use actively on weekdays and weekends
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	Use for visiting shops and local destinations, on weekdays and weekends
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	Use only on weekdays for commuting to distant workplace, etc.
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	Use only on weekdays for commuting to nearby workplace, etc.

2.1.3. Calculation of Reduction in Grid Power Usage

The reduction in grid power usage illustrated in Fig. 2-3 is calculated according to the balance between the power generated by the PV system and the surplus power that cannot be used for driving, with the unusable surplus power being decided by the charging state of the battery and the driving pattern.

The amount of power consumed by driving greatly differs according to the usage pattern of the vehicle. In this study, it was calculated using the six representative driving patterns set in 2.1.2.

Although the amount of power generated by onboard PV varies from day to day due to weather and the seasonal change in day length, during evaluation, the average amount of power generated per day was calculated from average annual solar radiation in Tokyo as a representative value. It was assumed that a constant amount of power is generated every day and that the vehicle and onboard PV system are always exposed to sunlight.

The calculation flow of reduction in grid power usage is shown in Fig. 2-7.

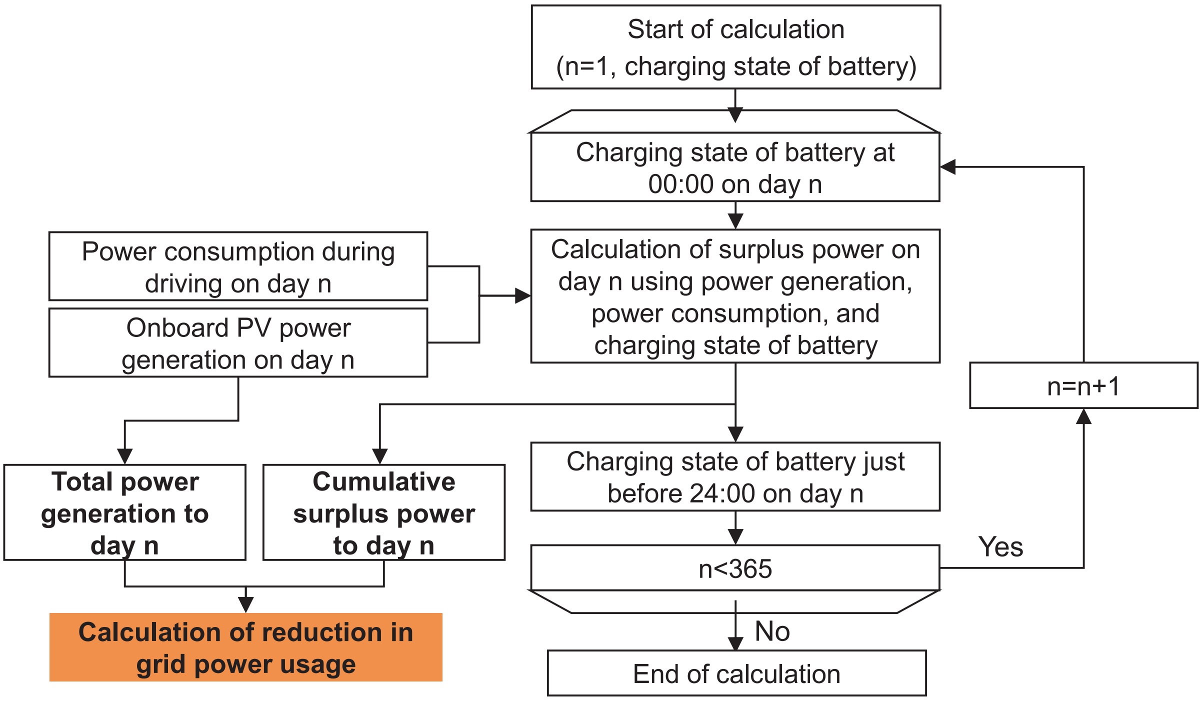


Fig. 2-7 Calculation flow of reduction in grid power usage

During evaluation, it was assumed that the power generated by the PV system is temporarily stored in a spare battery provided for the PV cell. This configuration is used in Toyota Prius PHV models that are fitted with onboard PV. By using a spare storage battery, it is possible to calculate the reduction in grid power usage by calculating net values of the generated power and power consumption on a daily basis without depending on what time of day the vehicle is driven.

2.2. Calculation of Added Value per PV-Powered Vehicle

(1) Prerequisites

Table 2-2 shows various prerequisites for calculating added value. Here, numerical values that are forecast to be achievable by 2030, when the commercialization of PV-powered vehicles is expected, were used as prerequisites.

The value of 1 kW was used as the estimated output of the PV modules installed on a vehicle. The highest efficiency of current PV modules is 31.17% achieved by NEDO/SHARP Corporation[3], and thus 31% was set as a level that will be sufficiently attainable in the future when onboard PV come into practical use. With this condition, the installation area for PV modules required to achieve an output of 1kW is 3.23 square meters as the horizontally projected area, which is substantially equal to the combined area of the roof and hood of HEVs, PHVs, and EVs currently on the market.

The value of 0.35 kg-CO_2/kWh[4] calculated based on the "New Policies Scenario" in the "World Energy Outlook 2015" published by IEA was used as the CO_2 emission factor of grid power in Japan.

Although the electric fuel economy of EV (i.e., the distance that a vehicle can travel per kWh) was reported to be in a wide range of 5.0 to 10.2 km/kWh depending on the season in a past study[5], in view of future advances in rechargeable battery technology and reductions in vehicle and battery weight, values of 12.5 km/kWh for EVs and 10.0 km/kWh for PHVs were used as the development target values to be attained by 2030 in NEDO's "Battery RM 2013".[6]

As the fuel consumption of a HEV, the value of 47.6 km/l that is the JC08 mode fuel economy of a concept car announced by a Japanese car manufacturer at the Geneva Motor Show in 2012 was used as the future development target.

The price of onboard PV was set at 120,000 JPY/kW based on NEDO's development target price for Type III-V PV systems. This system target price includes the cost of components, such as a supporting structure and some balance of systems (BOS), which are unnecessary when mounting on a vehicle, so the price of onboard PV may be lower than this price if the development target is achieved.

Based on NEDO's "Battery RM 2013," the battery capacity was assumed to be 40 kWh per vehicle for an EV and 10 kWh per vehicle for a PHV[6]. Although the battery capacity of an HEV was assumed to be 1.3 kWh per vehicle based on the present value, it is assumed that a supplementary battery for temporarily storing power generated by onboard PV is also provided, with this supplementary battery having sufficient capacity to store the average daily amount of generated power (i.e., an effective capacity of 2.6 kWh).

Based on the latest statistical data, the average usage period of a vehicle was set at 12 years[7]. The lifecycle CO_2 emissions of a PV system were given by dividing the lifetime CO_2 emissions of PV equipment that uses crystalline silicon PV cells reported in past studies as 1.17 tons (an emission factor of 0.059 kg-CO_2/kWh assuming twenty years of power generation)[8] by the amount of power generated by onboard PV during the average usage period of a vehicle for 12 years.

Since low-voltage power of 100V to 200V is generally used to charge EVs and PHVs, the unit price of power purchased by users from a power company to charge a vehicle was set at 25.5 JPY/kWh[9], the 2014 national average price of domestic electricity calculated by The Federation of Electric Power Companies of Japan. The price of gasoline consumed in hybrid cars was set at the average retail price of 133 JPY/l[10] in FY2015 from statistics produced by the Agency for Natural Resources and Energy.

As the amount of solar radiation, the value for the Tokyo metropolitan area in the NEDO's solar irradiation database[11] was used, and the power loss factor during power generation was set according to past studies[12] at 0.739. This loss factor includes a DC/DC conversion efficiency of 0.9 by a power conditioner (PCS), a charging loss factor of 0.95 for the battery, a temperature correction coefficient of 0.91, and a maximum power point tracking (MPPT) loss factor of 0.95. Power consumption by the control unit (ECU) of 0.12 kWh/day was also taken into account.

Table 2-2 List of prerequisites for analyzing added value

Parameter				Source
PV cell	PV cell output	1.0	kW/vehicle	Estimated value
	PV module efficiency (Achieved in 2016)	31	%	Efficiency of type III-V PV modules achieved in 2016[3]
	PV cell area	3.23	m^2	(=PV cell output ÷ Module efficiency)
	Target price for onboard PV (as of 2030)	120,000	JPY/kW	NEDO's development target for type III-V PV systems
EV	Electric fuel economy	12.5	km/kWh	Estimated value for 2030 in NEDO's "Battery RM 2013"[6]
	Battery capacity	40	kWh/vehicle	Estimated value for 2030 in NEDO's "Battery RM 2013"[6]
PHV	Electric fuel economy	10	km/kWh	Estimated value for 2020 in NEDO's "Battery RM 2013"[6]
	Battery capacity	10	kWh/vehicle	Estimated value for 2020 in NEDO's "Battery RM 2013"[6]
HEV	Electric fuel economy	10	km/kWh	Value for Prius PHV
	Battery capacity	1.3	kWh/vehicle	Value for 4th generation Prius
	HEV fuel consumption	47.6	km/L	Geneva Motor Show, 2012
EV, PHV, HEV	Average usage period of vehicle (2015 actual data)	12	years	Statistics information by Automobile Inspection & Registration Information Association[7]
CO_2 emission factor: PV		0.099	kg-CO_2/kWh	Calculated by dividing lifecycle CO_2 emissions of domestic polycrystalline PV cells by the amount of power generated by onboard PV over 12 years based on "Life cycle analysis of photovoltaic power generation system"[8] by Mizuho Information & Research Institute
CO_2 emission factor: Grid power		0.35	kg-CO_2/kWh	IEA: World Energy Outlook 2015, 2015[4]
CO_2 emission factor: Gasoline		2.322	kg-CO_2/l	"Ministerial Ordinance Concerning Calculation of Greenhouse Gas Emissions Associated with Business Activities of Specified Emitters" by Ministry of Economy, Trade and Industry and Ministry of the Environment
Grid power price		25.5	JPY/kWh	Calculated from national average price of metered electricity in 2014 by using "Handbook of Electric Power Industry in FY2015 edition" by the Statistics Committee of Federation of Electric Power Companies of Japan[9]
Gasoline retail price		133	JPY/L	Average price in FY2015 from "Gas Station Retail Price Survey (gasoline, diesel, kerosene)": Agency for Natural Resources and Energy[10]

(2) Quantification of Added Value of Onboard PV

i. EV case

1) Relationship between Utilization of Onboard PV-Derived Power and Added Value

For an EV as the base vehicle, the relationship between the proportion (0% to 100%) of onboard PV-generated power used for driving, the economic benefit, and the reduction in CO_2 emissions was analyzed. The results are shown in Fig. 2-8.

As a result of analyzing the economic benefit when the utilization of onboard PV-generated power is in the range of 0% to 100%, it was demonstrated that when the utilization of onboard PV-generated power is 42% or higher, there is a merit that the cost to the user when installing a PV system is lower than when not installing a system. However, when utilization is below 42%, there is no merit to installing a PV system.

In the same way, as a result of analyzing the effect of reducing CO_2 emissions, it was established that when the utilization of onboard PV-generated power is below 28%, the reduction in CO_2 emissions is negative, that is, the amount of CO_2 emitted by the manufacturing, usage, and disposal of the PV system exceeds the amount of reduction in CO_2 emissions achieved by reducing the use of grid power, resulting in a net increase in CO_2 emissions. This indicates that when there is a large surplus of generated power, such as when the distance driven by the user is short, the onboard PV system has no effect.

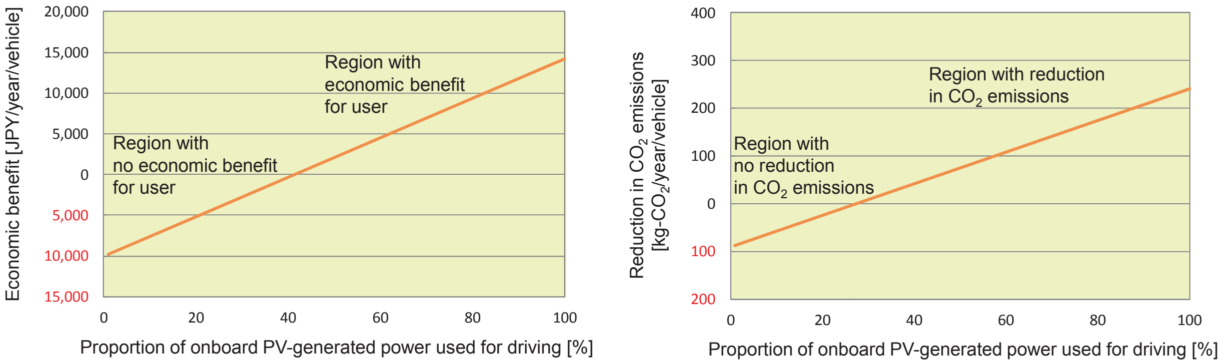


Fig. 2-8 Relationship between utilization of onboard PV-derived power, reduction in CO_2 emissions, and economic benefit for EV

2) Mapping of Added Value According to Usage Patterns

Next, the reduction in CO_2 emissions and economic benefit were analyzed by varying the driving distance per day and the driving frequency for an EV (with a battery capacity of 40 kWh) fitted with an onboard PV system. A graph produced by mapping the results is given in Fig. 2-9.

Since an EV has a large battery capacity, almost all onboard PV-generated power can be used. The regions where a reduction in CO_2 emissions and an economic effect can be expected are large.

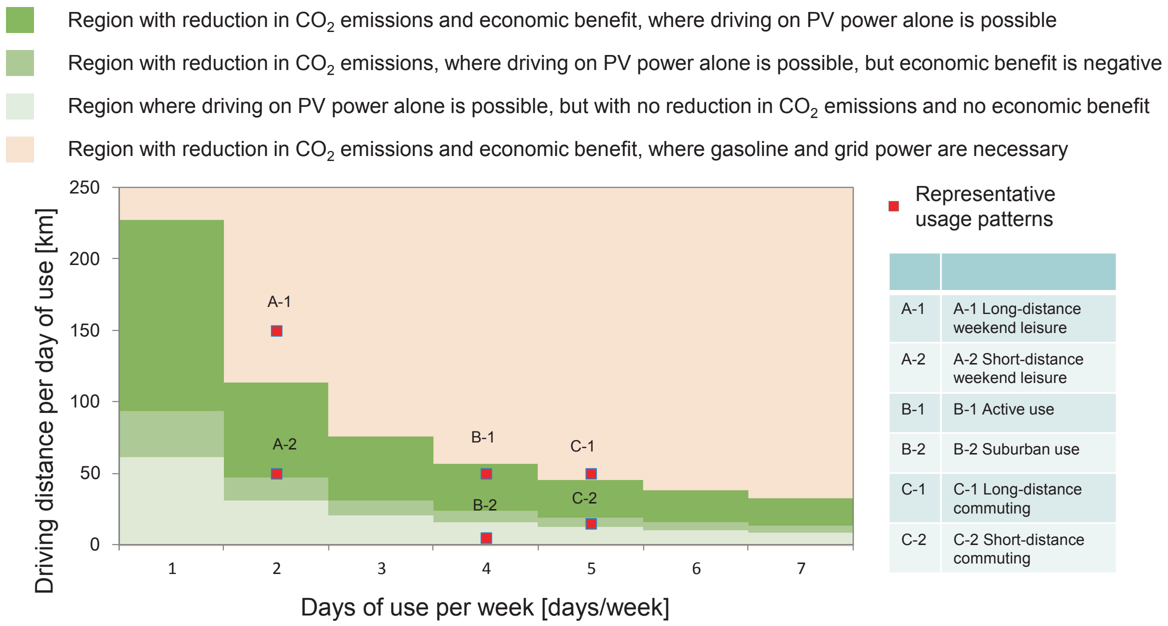


Fig. 2-9 Mapping of added value according to usage patterns of EV

3) Quantification of Added Value for Representative Usage Patterns

From Fig. 2-8, it can be seen that the proportion of onboard PV-generated power that is usable is an important variable for both the reduction in CO_2 emissions and the economic benefit, which greatly change accordingly. For usage patterns like C-1 and A-1 where the total driving distance per week is long, both the economic benefit and reduction in CO_2 emissions are large. On the other hand, for usage patterns such as A-2 and C-2 where the total driving distance per week is short, the amount of power consumed during driving is smaller than the total power generated in one week, resulting in power generated by the onboard PV system overflowing from the battery and a low proportion of onboard PV-generated power being usable. As shown in Table 2-3, the added value is therefore small compared to other cases.

Table 2-3 Economic benefit and reduction in CO_2 emissions for each usage pattern of EV

Pattern	Type	Driving distance per journey (km)	Proportion of usable onboard PV-generated power	Economic benefit (JPY/vehicle/year)	Reduction in CO_2 emissions (kg-CO_2/vehicle/year)
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	100%	14,200	240
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	44%	650	54
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	88%	11,300	200
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	9%	-7,820	-23
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	100%	14,200	240
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	33%	-2,010	18

・A negative economic benefit indicates that installing a PV system works out more expensive to the user than not installing a system. A negative reduction in CO_2 emissions indicates that CO_2 emissions actually increase.

The usage pattern B-2 is for light users who only drive their cars 20 km a week. Since only 9% of the onboard PV-generated power is used, the reduction in CO_2 emissions is negative. For light users like the B-2 pattern, the amount of power required for driving can be generated using a smaller PV system than the 1 kW system assumed here, and the CO_2 emissions derived from onboard PV will fall; therefore, it is possible to improve the net reduction in CO_2 emissions. This suggests that to increase added value in situations where there is surplus power that cannot be used, it is also important to select a suitable PV cell capacity for the usage pattern.

Next, the change in the number of charging cycles due to the introduction of onboard PV was calculated. The results are shown in Table 2-4. For usage patterns excluding A-1 and C-1, it is possible to become completely charging-free, which improves user convenience. Conversely, for usage patterns like A-1 and C-1 where the driving distance is long and power consumption is high, the amount of power required for driving will exceed the power generated by onboard PV, so such power cannot be completely covered by onboard PV. To achieve complete energy independence, a larger-capacity PV cell needs to be installed (1,270 W for A-1 and 1,070 W for C-1 (see Table 3-1)).

Table 2-4 Improvement in convenience for each usage pattern of EV

Pattern	Type	Driving distance per journey (km)	Charging cycles with onboard PV
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	Fewer charging cycles, but still necessary
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	Zero cycles per year attainable
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	Zero cycles per year attainable
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	Zero cycles per year attainable
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	Fewer charging cycles, but still necessary
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	Zero cycles per year attainable

ii. PHV case

1) Relationship between Utilization of Onboard PV-Derived Power and Added Value

The battery capacity of a PHV is comparatively small at 10 kWh, and as shown in Fig. 2-11, for usage patterns where the vehicle is driven only one or two days a week, there are cases where generated power cannot be used due to a lack of free battery capacity. For example, when the vehicle is driven only one day a week, the power generated by onboard PV during the six days with no driven is 15.6 kWh (=2.6 kWh/day), which exceeds the total capacity of the onboard battery, resulting in power overflowing from the battery. If an energy management system, such as Vehicle to Home (V2H) for supplying power stored in an onboard battery to the home, could be used, it would be possible to make effective use of the power generated by the onboard PV system.

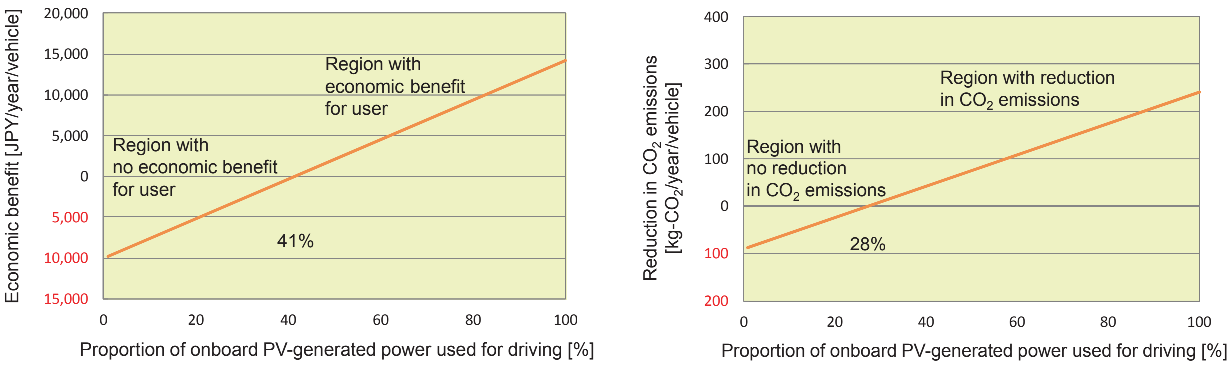
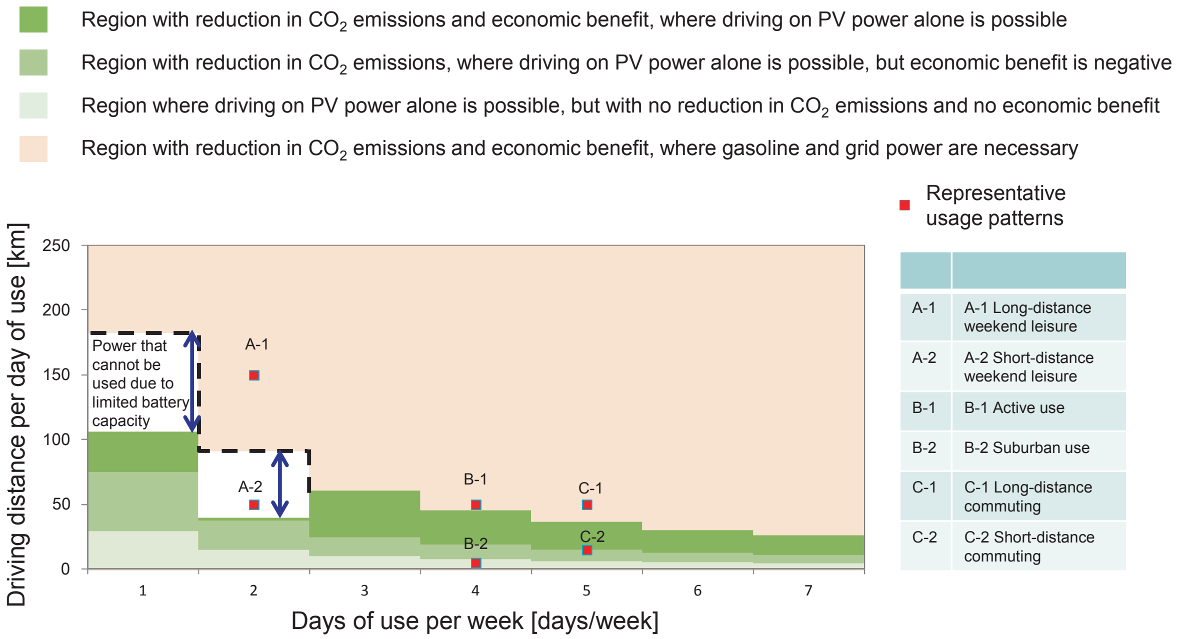


Fig. 2-10 Relationship between utilization of onboard PV-derived power and added value for PHV

2) Mapping of Added Value According to Usage Patterns

A graph produced by mapping the calculated results of added value for each usage pattern of a PHV is given in Fig. 2-11. Since a PHV has a battery capacity of 10 kWh per vehicle that is one quarter of that of an EV, when a vehicle is driven one or two days a week, there are cases where the power generated by onboard PV cannot further charge the battery and overflows. Although this limited battery capacity is not problematic when the vehicle is driven three or more days a week, since the electric fuel economy of a PHV is 20% lower than that of an EV, the region in which the energy used by driving is completely covered by onboard PV-generated power is smaller than for an EV.



A-1	A-1 Long-distance weekend leisure
A-2	A-2 Short-distance weekend leisure
B-1	B-1 Active use
B-2	B-2 Suburban use
C-1	C-1 Long-distance commuting
C-2	C-2 Short-distance commuting

Fig. 2-11 Mapping of expected added value according to usage patterns of PHV

3) Quantification of Added Value for Representative Usage Patterns

The proportion of onboard PV-generated power that is usable is an important variable for both the economic benefit and the reduction in CO_2 emissions, which greatly change accordingly. The economic benefit and the reduction in CO_2 emissions are shown for each usage pattern of a PHV in Table 2-5. Since the electric fuel economy and battery capacity of a PHV differ from these of an EV and it is possible to switch to running on gasoline when all of the power in the battery has been used up, the reduction in CO_2 emissions and economic benefit differ from those of an EV, even for the same usage pattern.

For a PHV also, in C-1, since power generated by onboard PV does not overflow from the battery, a large added value is expected as in the case with an EV. On the other hand, for the pattern A-1 where the vehicle is used a few days a week, the low capacity of the battery reduces the added value of onboard PV compared to an EV. When onboard PV systems are installed on PHVs, a reduction in CO_2 emissions is achieved in patterns where the vehicle is driven at least three days a week.

Table 2-5 Economic benefit and reduction in CO_2 emissions for each usage pattern of PHV

Pattern	Type	Driving distance per journey (km)	Proportion of usable onboard PV-generated power	Economic benefit (JPY/vehicle/year)	Reduction in CO_2 emissions (kg-CO_2/vehicle/year)
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	56%	3,550	94
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	44%	650	54
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	88%	11,300	200
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	9%	-7,820	-23
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	100%	14,200	240
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	33%	-2,010	18

iii. HEV case

1) Relationship between Utilization of Onboard PV-Derived Power and Added Value

In the same way as for an EV, the relationship between the utilization of onboard PV-generated power (0% to 100%) and the reduction in CO_2 emissions and economic benefit achieved by replacing gasoline consumption is shown in Fig. 2-12. When the utilization of onboard PV-generated power is 38% or below, the economic benefit is negative. In the same way, when the utilization of onboard PW-generated power is below 20%, the reduction in CO_2 emissions is also negative.

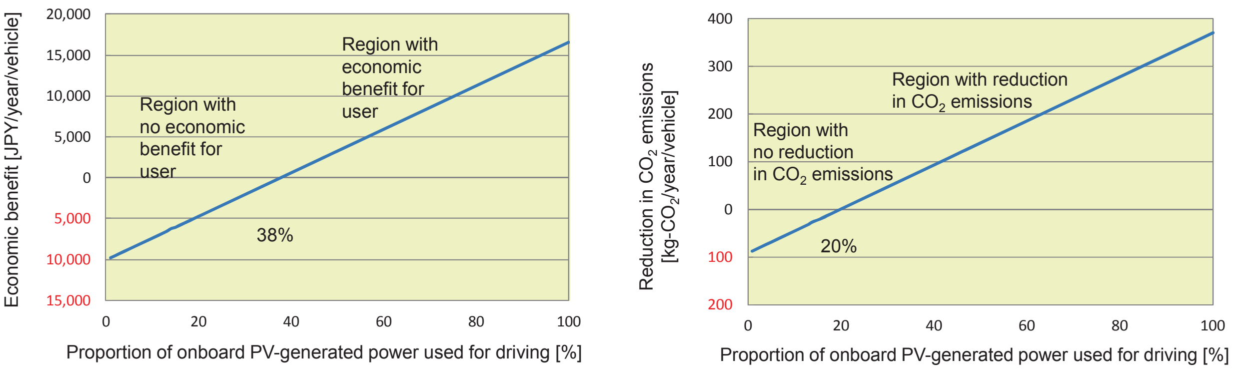
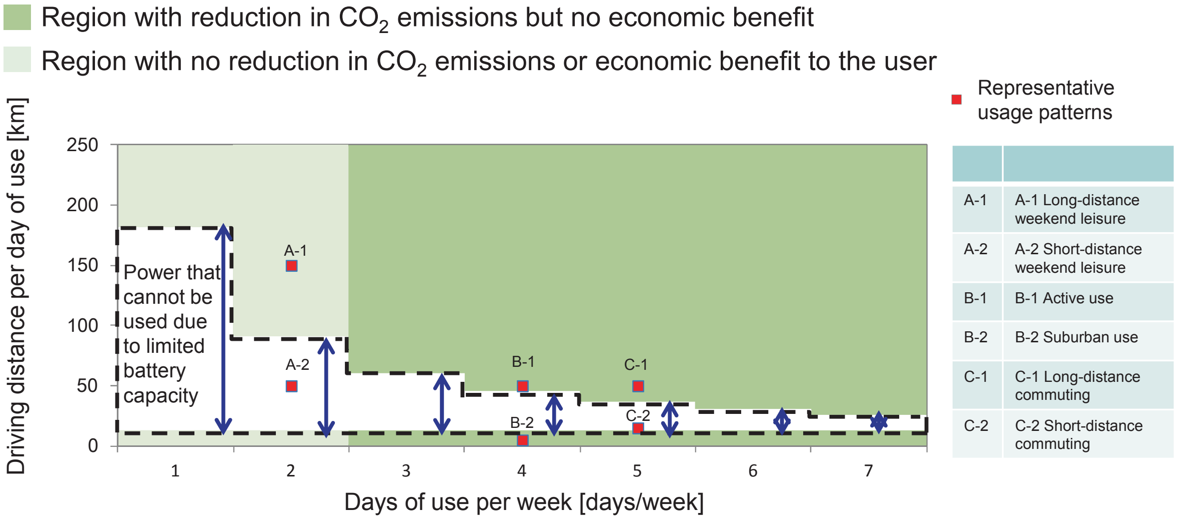


Fig. 2-12 Relationship between utilization of onboard PV-derived power and added value for HEV

2) Mapping of Added Value According to Usage Patterns

In this analysis, the average power generated per day by a 1 kW onboard PV system is 2.6 kWh and larger than the onboard battery capacity of an HEV. In view of this battery capacity, a maximum of 1.3 kWh can be used per day (around 50%), and any extra power is a surplus. In this case, regardless of the number of times the vehicle is driven per week, the distance that can be driven per day is 13 km (=1.3 kWh, with the extra generated power as a surplus).

As a result, a reduction in CO_2 emissions is achieved only when the vehicle is driven at least three days a week, and there is no reduction in CO_2 emissions when driven for two or fewer days a week. It was established that since the onboard battery capacity of an HEV is small, it is not possible to effectively use the power generated by a 1 kW PV cell.



A-1	A-1 Long-distance weekend leisure
A-2	A-2 Short-distance weekend leisure
B-1	B-1 Active use
B-2	B-2 Suburban use
C-1	C-1 Long-distance commuting
C-2	C-2 Short-distance commuting

Fig. 2-13 Mapping of expected added value for usage patterns of HEV

3) Quantification of Added Value for Representative Usage Patterns

The economic benefit and reduction in CO_2 emissions for each usage pattern of an HEV are shown in Table 2-6. Due to the smaller battery capacity of an HEV, the onboard battery becomes fully charged in one day. Since it is not possible to effectively use the power generated by onboard PV, the economic benefit and reduction in CO_2 emissions are small compared to those of an EV and a PHV.

On the other hand, like C-2, it is possible to achieve a larger reduction in CO_2 emissions than an EV and a PHV for patterns with a higher driving frequency and shorter driving distance. Since the CO_2 emission factor of gasoline is larger than that of grid power, as shown in Fig. 2-12, it is possible to achieve a reduction in CO_2 emissions with an HEV even if the utilization of onboard PV-generated power is lower.

For an HEV, with patterns C-1 and C-2 where short distances are frequently driven, the added value is larger than for an EV or a PHV.

Table 2-6 Economic benefit and reduction in CO_2 emissions for each usage pattern of HEV

Pattern	Type	Driving distance per journey (km)	Proportion of usable onboard PV-generated power	Economic benefit (JPY/vehicle/year)	Reduction in CO_2 emissions (kg-CO_2/vehicle/year)
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	14%	-6,200	-25
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	14%	-6,200	-25
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	29%	-2,400	41
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	11%	-7,080	-40
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	33%	-520	73
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	33%	-520	73

(3) Summary for Analysis of Expected Added Value

Looking at individual cases, in the C-1 usage pattern for long-distance commuting, the reduction in CO_2 emissions and economic benefit are larger for all types of vehicles. Since the battery capacity of an HEV is small, both the economic benefit and the reduction in environmental impact are normally small, but for the C-2 usage pattern for short-distance commuting, the reduction in environmental impact is larger than for an EV or a PHV. This is because the amount of CO_2 emissions from gasoline that is the baseline for calculating the benefit is large compared to electrical power. This suggests that although an HEV cannot make effective use of all power generated by onboard PV due to the limited capacity of the battery, since the generated power will replace gasoline, any effective use of generated power has a large potential for reducing CO_2 emissions.

There is a tradeoff between user convenience, that is, a reduction in frequency of charging, and the reduction in CO_2 emissions and the economic benefit. For a user who drives long distances, it is possible to use 100% of the onboard PV-generated power and achieve a large reduction in CO_2 emissions and economic benefit. However, grid charging is required for shortfalls in power, so it is not possible to enjoy the convenience of making a vehicle charging-free. Note that although not evaluated in this study, aside from making a vehicle charging-free, the onboard PV system could potentially improve convenience by utilizing surplus power for air conditioning to improve interior comfort when the vehicle is parked in strong sunlight.

Table 2-7 Summary of added value for each usage pattern

Pattern	Type	Driving distance per journey (km)	Economic benefit (JPY/vehicle /year)	Reduction in CO_2 emissions (kg-CO_2/ vehicle/year)	Convenience (reduction in frequency of charging: for EV case only)
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	EV : 14,200 PHV : 3,550 HEV : -6,200	EV : 240 PHV : 94 HEV : -25	Fewer frequency of charging, but still necessary
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	EV : 650 PHV : 650 HEV : -6,200	EV : 54 PHV : 54 HEV : -25	No charging per year attainable
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	EV : 11,300 PHV : 11,300 HEV : -2,400	EV : 200 PHV : 200 HEV : 41	No charging per year attainable
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	EV : -7,820 PHV : -7,820 HEV : -7,080	EV : -23 PHV : -23 HEV : -40	No charging per year attainable
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	EV : 14,200 PHV : 14,200 HEV : -520	EV : 240 PHV : 240 HEV : 73	Fewer frequency of charging, but still necessary
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	EV : -2,010 PHV : -2,010 HEV : -520	EV : 18 PHV : 18 HEV : 73	No charging per year attainable

2.3. Expected Added Value in the Future

This section estimates the possible reduction in CO_2 emissions in the future when PV systems are installed on next generation vehicles, based on the expected introduction of next generation vehicles.

2.3.1. Contribution to Reduction in CO_2 Emissions in Transport Sector

(1) Future Introduction of PV-Powered Vehicles

i. Cumulative Number of Next Generation Vehicles Introduced in the Future

The cumulative number of EVs, PHVs, and HEVs introduced (i.e., the number of vehicles owned) by 2030 and 2050 were estimated based on the annual sales figures given in a past study[13]. These figures omit trucks, buses, and ultra-compact mobility vehicles. The usage year of vehicles was assumed as 12 years, and numbers for 2050 were estimated by extrapolating an increasing trend from 2025 to 2035. Projected numbers of next generation vehicles are shown in Fig. 2-14 to Fig. 2-16.

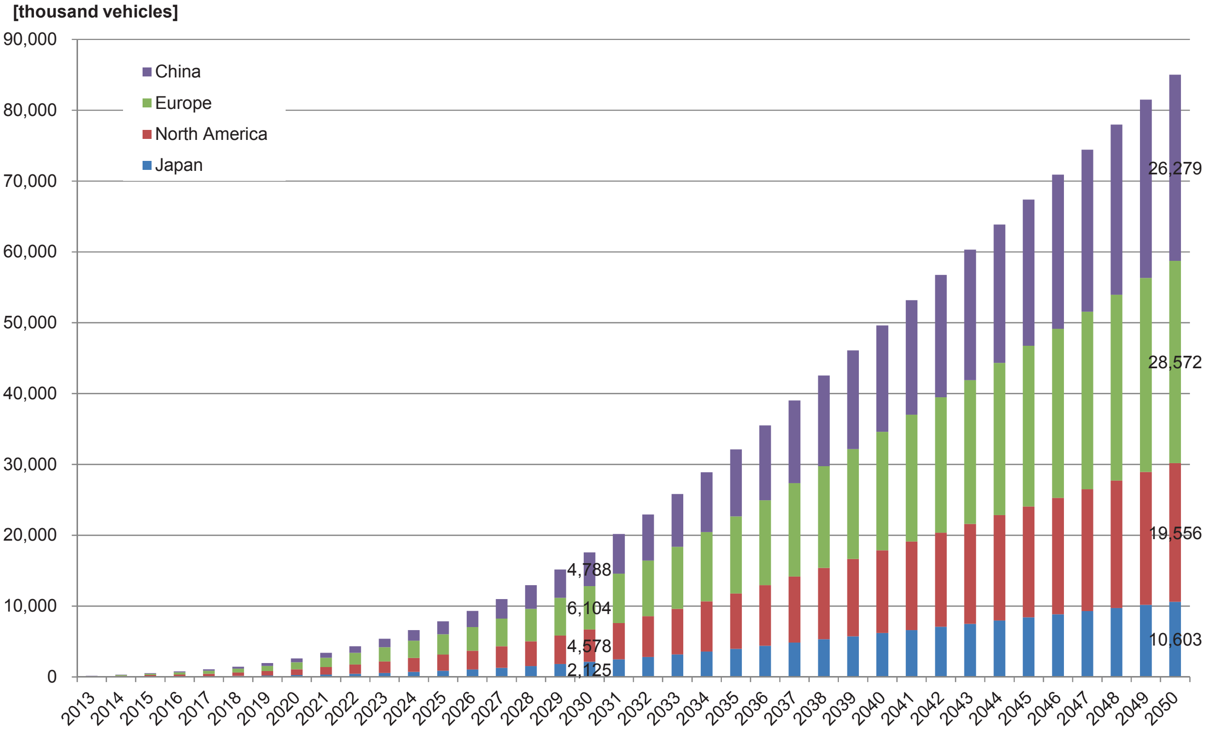


Fig. 2-14 Projected cumulative number of EVs

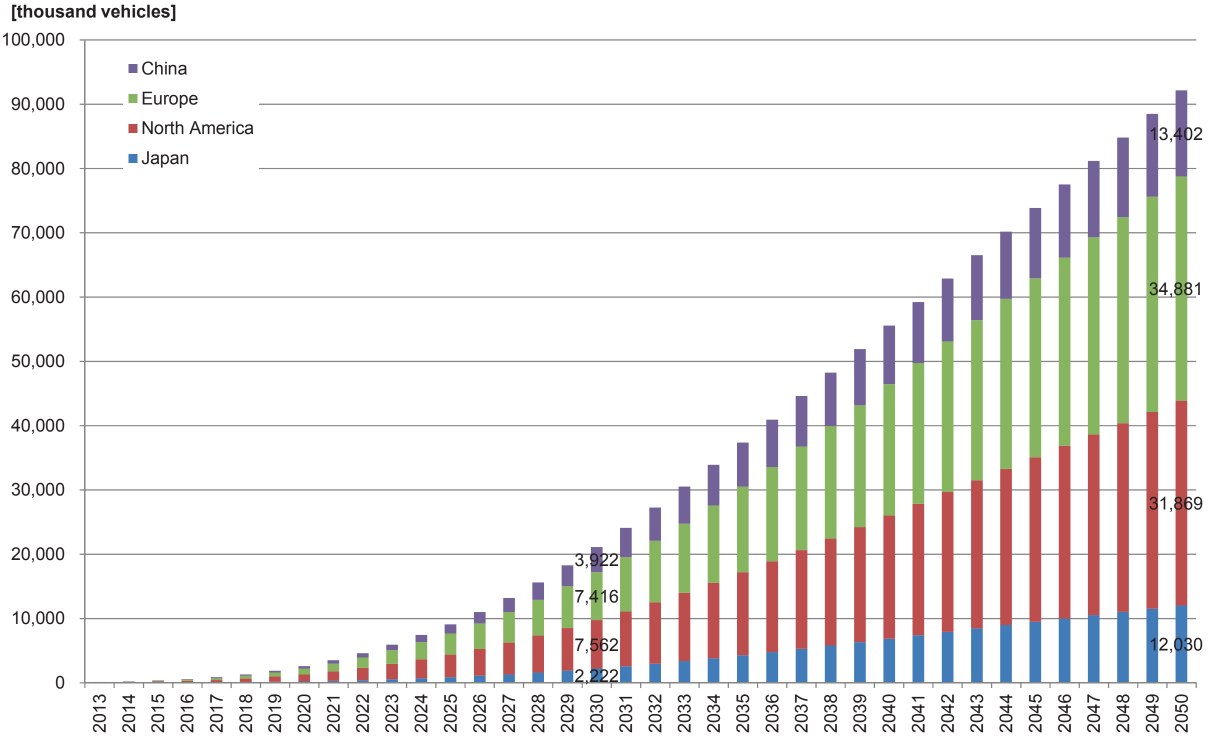


Fig. 2-15 Projected cumulative number of PHVs

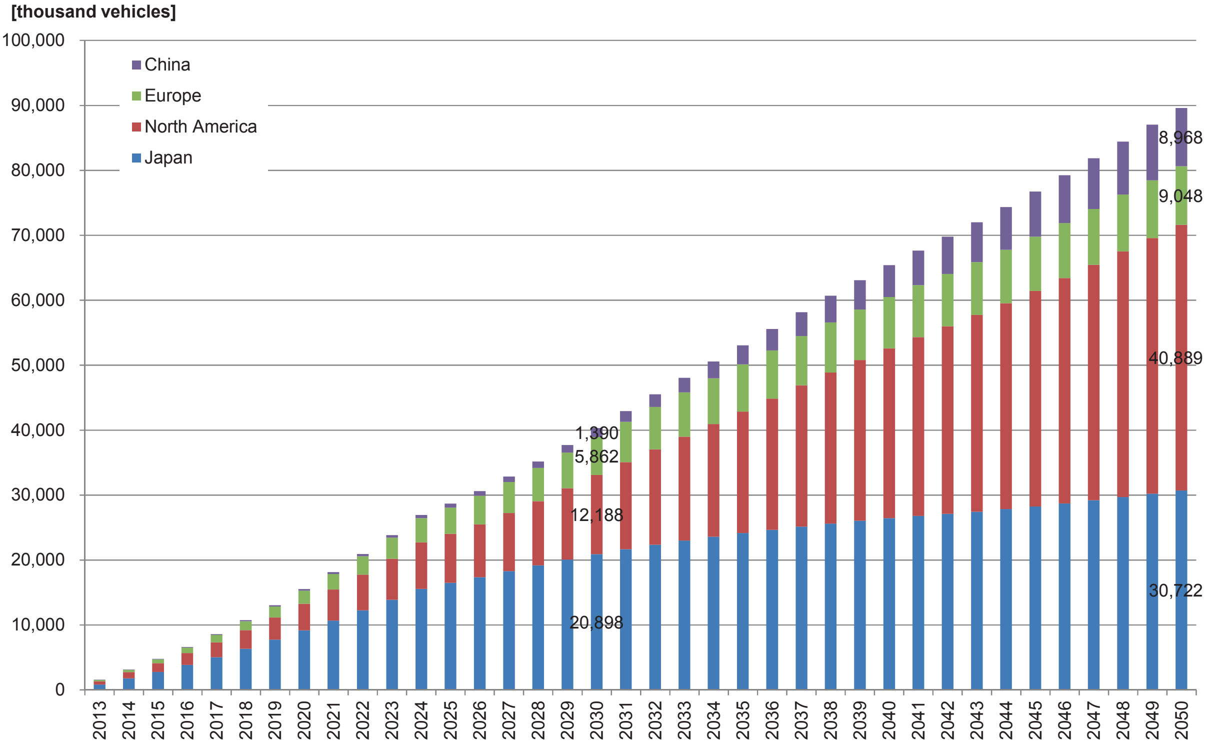


Fig. 2-16 Projected cumulative number of HEVs

ii. Cumulative Number of PV-Powered Vehicles in Japan

Two scenarios, Scenario 1 and Scenario 2, were used to estimate the proportion of future next generation vehicles introduced that are PV-powered in Japan. In Scenario 1, it was assumed that PV-powered vehicles go on sale in 2018 and the proportion of next generation vehicles that are PV-powered is 100% from 2018 onwards. In Scenario 2, it was assumed that PV-powered vehicles go on sale in 2025 and the proportion of next generation vehicles that are PV-powered rises to become 100% from 2029 onwards (20% in 2025, 40% in 2026, 60% in 2027, and 80% in 2028). The projected cumulative number of PV-powered vehicles introduced in Japan in each scenario is shown in Fig. 2-17 and Fig. 2-18.

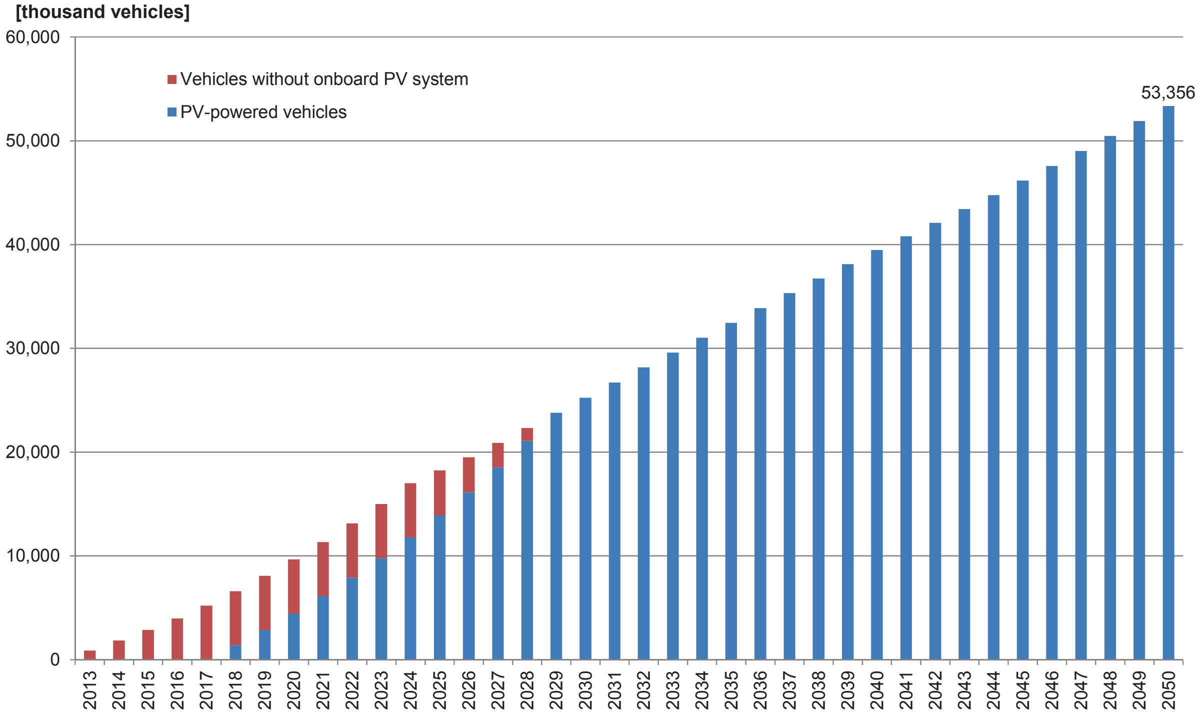


Fig. 2-17 Projected cumulative number of PV-powered vehicles introduced in Japan in Scenario 1

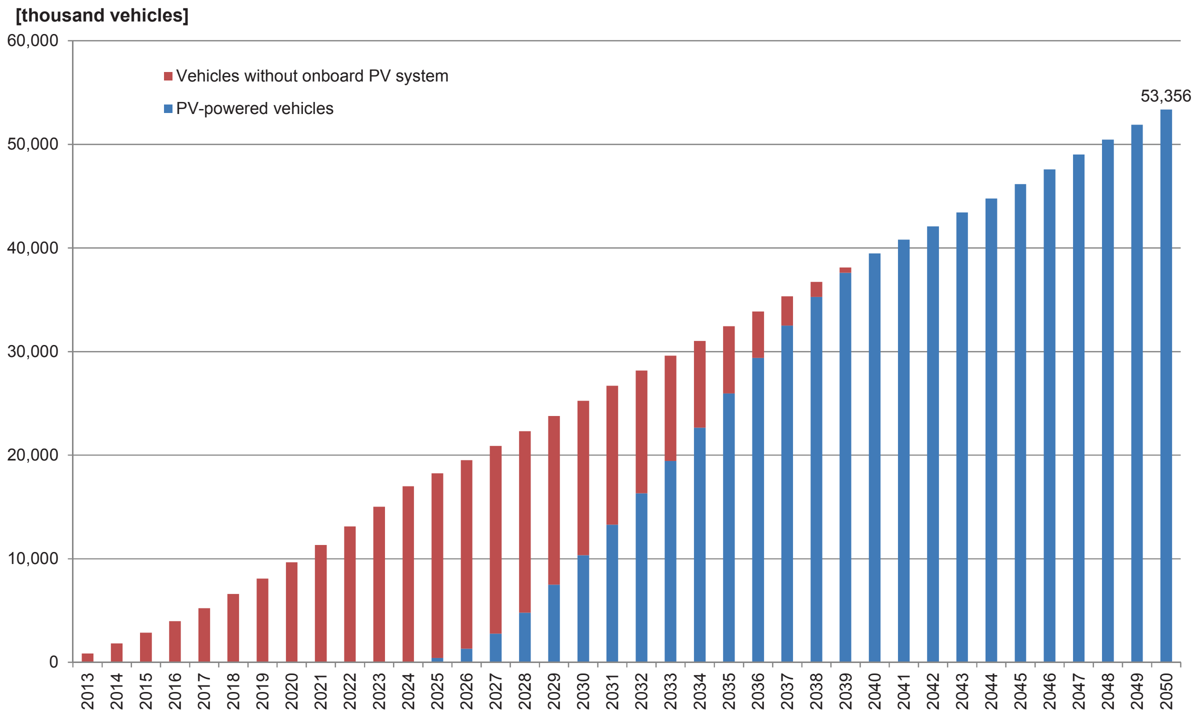


Fig. 2-18 Projected cumulative number of PV-powered vehicles introduced in Japan in Scenario 2

(2) Reduction in CO_2 Emissions and Contribution to Reduction in Transport Sector in Japan

Table 2-8 shows the reduction in CO_2 emissions in Japan as a whole in 2030 and 2050 calculated from the estimated number of PV-powered vehicles introduced as given in (1) above and the reduction in CO_2 emissions per vehicle calculated in Section 2.2. For the reduction in CO_2 emissions per vehicle, the largest reduction in each usage pattern was used. The baseline for the reduction in CO_2 emissions is the amount of emissions for a case where next generation vehicles without onboard PV cells are widely adopted.

The annual reduction in CO_2 emissions of PV-powered vehicles in 2030 is up to 2.27 million t-CO_2/year in Scenario 1 and up to 1.03 million t-CO_2/year in Scenario 2. Out of the assumed reduction in CO_2 emissions by passenger cars in Japan by 2030, Scenario 1 accounts for 11% and Scenario 2 accounts for 5%.

Table 2-8 Reduction in CO_2 emissions due to PV-powered vehicles and contribution to reduction in transport sector in Japan

Assumed adoption of PV-powered vehicles	Year	Reduction in CO_2 emissions due to PV-powered vehicles (A)	Reference for calculating possible contribution due to PV-powered vehicles (B)		Ratio (A/B)
Scenario 1: All next generation vehicles (passenger cars) owned in 2030 are PV-powered.	2030	Up to 2.27 million t-CO_2	CO_2 reduction target for passenger cars in 2030 in Japan	20 million tons	11%
	2050	Up to 5.91 million t-CO_2	CO_2 reduction target for passenger cars in 2050 in Japan	64 million tons	9%
Scenario 2: Some next generation vehicles (passenger cars) owned in 2030 are PV-powered.	2030	Up to 1.03 million t-CO_2	CO_2 reduction target for passenger cars in 2030 in Japan	20 million tons	5%
	2050	Up to 5.91 million t-CO_2	CO_2 reduction target for passenger cars in 2050 in Japan	64 million tons	9%

* Reduction in CO_2 emissions required to achieve 80% reduction target by 2050: 960 million tons (for Japan as a whole), of this 200 million tons in the transport sector, including 64 million tons for passenger cars (Contribution of standalone measures in the transport sector: 58.4 %, Percentage of total vehicle CO_2 emissions from passenger cars: 55.2%).

* CO_2 emission factor for grid-derived power in 2030 was based on 〝New Policies Scenario 2030〟 in 〝IEA World Energy Outlook 2015〟. As for CO_2 emission factor for grid-derived power in 2050, that in 2040 in 〝New Policies Scenario 2040〟 in 〝IEA World Energy Outlook 2015〟 was used. CO_2 emission factor of gasoline in Japan was used for calculations on HEV.

(3) Reduction in CO_2 Emissions in Overseas Regions

The respective reductions in CO_2 emissions in 2030 and 2050 in North America, Europe and China when onboard PV systems are installed on all next generation vehicles in the regions based on the Scenario 1 in (1) were calculated. Although the reduction in CO_2 emissions per vehicle will differ according to the usage patterns, the highest values out of the usage patterns in Japan were used after making adjustments with the CO_2 emission factor for grid-derived power in each region. Note that since the 2040 data given in "IEA World Energy Outlook" was used for the CO_2 emission factor for grid-derived power in 2050, there is potential for the actual CO_2 emission factor to further fall below this. Note also that actual usage patterns of vehicles in these regions can differ from those in Japan.

Table 2-9 Reduction in CO_2 emissions in overseas regions in 2030 and 2050

[t-CO_2]	Japan		North America		Europe		China	
	2030	2050	2030	2050	2030	2050	2030	2050
EV	505,750	1,919,143	1,089,564	3,911,200	701,960	1,657,176	2,006,172	9,250,208
PHV	528,836	2,177,430	1,799,756	6,373,800	852,840	2,023,098	1,643,318	4,717,504
HEV	1,232,982	1,812,598	719,092	2,412,451	345,858	533,832	82,010	529,112
Total	2,267,568	5,909,171	3,608,412	12,697,451	1,900,658	4,214,106	3,731,500	14,496,824

* CO_2 emission factor for grid-derived power in 2030 was based on 〝New Policies Scenario 2030〟 in 〝IEA World Energy Outlook 2015〟,with North America using data for USA. As for CO_2 emission factor for grid-derived power in 2050, that in 2040 in 〝New Policies Scenario 2040〟 in 〝IEA World Energy Outlook 2015〟, with North America using data for USA was used. CO_2 emission factor of gasoline in Japan was used for calculations on HEV.

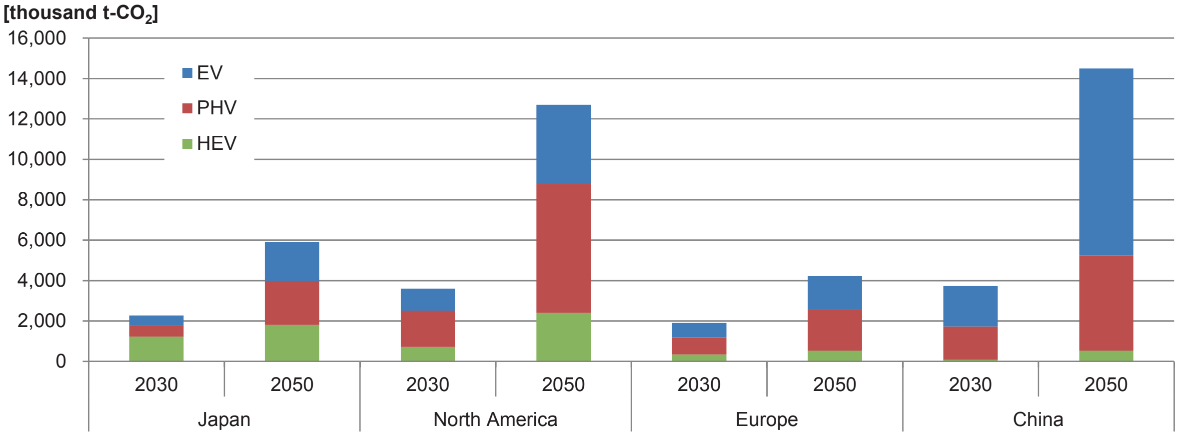


Fig. 2-19 Reduction in CO_2 emissions in overseas regions in 2030 and 2050

3. Issues Relating to Development and Adoption of PV-Powered Vehicles and Future Initiatives

Going forward, with the aim of widespread adoption of PV-powered vehicles in society, technical challenges to be overcome in realizing PV-powered vehicles and issues relating to their promotion are considered. In this section, in addition to examining the current trends for PV-powered vehicles obtained through this study, potential issues are identified and proposals are devised as to how best to proceed.

3.1. Direction for PV-Powered Vehicles

3.1.1. Direction for Passenger Vehicles

As shown in Table 3-1, the optimal capacity of a PV cell to be installed on a next generation vehicle depends on the usage pattern. The "optimal capacity" refers to a capacity where 100% of the PV-generated power can be used and charging with grid power is unnecessary in each usage pattern, and indicates a PV cell capacity that maximizes the economic benefit and reduction in CO_2 emissions.

When the onboard battery is 40 kWh, a capacity of the 1 kW level is optimal for long-distance usage, and 500 W or below is optimal for short-distance usage. However, in terms of technical development, a 1 kW onboard PV cell, which can provide superior convenience and environmental benefits for a wide range of users up to long-distance drivers, should be set as the target. Also, in view of the current trend for increased battery capacity in vehicles, and taking into account the possibility of even larger battery capacity in the future, a 1 kW or larger onboard PV cell capacity would be necessary.

Table 3-1 PV capacity that maximizes economic benefit and reduction in CO_2 emissions

Pattern	Type	Average driving distance per day of use (km)	[Reference] Conversion to annual driving distance	Optimal PV capacity (for 40 kWh battery)
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	15,600 km/yr.	1,270 W
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	5,200 km/yr.	460 W
B. Weekday/ weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	10,400 km/yr.	870 W
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	1,000 km/yr.	130 W
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	13,000 km/yr.	1,070 W
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	3,900 km/yr.	350 W

Regarding the installation of a 1 kW PV cell on a passenger car, it is first necessary to investigate the actual surface area of the vehicle where a PV cell can be installed. As shown in Table 3-2, the horizontally projected surface area of a typical passenger car that is not occupied by glass or lights is usually below 3.5 m^2. This means that 30% or higher efficiency PV cell is needed to install a 1kW PV system.

Table 3-2 Calculation of PV-mountable area of existing cars

Type	① Rooftop (m^2)	② Hood (m^2)	Total Area (m^2)
PHV (Company A, Japan)	1.9	0.9	2.8
HEV (Company A, Japan)	2.0	0.9	2.9
EV (Company B, Japan)	2.0	0.7	2.7
PHV (Company C, Japan)	2.4	1.3	3.7
EV (Company C, Japan)	1.9	0.1	2.0
EV (Company D, Japan)	2.3	0.8	3.1
PHV (Company X, overseas)	2.3	1.4	3.6
EV (Company Y, overseas)	2.2	1.7	3.9
EV (Company Z, overseas)	2.2	0.7	2.9

･Calculated using horizontally projected drawings in catalogs published by the respective manufacturers
･The PV-mountable area was calculated as the area aside from glass, lights, number plates, front grills, antennas, etc.

Table 3-3 shows the proportion of the power generated by a 1 kW onboard PV cell that can be utilized by the vehicle. Since there will be excess power especially when the vehicle is only driven short distances, it is important to study how to establish a social system that can make effective use of this surplus power.

Table 3-3 Vehicle usage and usable proportion of power generated by onboard 1 kW PV

Pattern	Type	Average driving distance per day of use (km)	Proportion of usable onboard 1kW PV-generated power	Economic benefit (JPY/vehicle/year)	Reduction in CO_2 emissions (kg-CO_2/vehicle/year)
A. Weekend use	A-1: Long-distance weekend leisure	150 km for 2 days (Sat. and Sun.)	100%	14,200	240
	A-2: Short-distance weekend leisure	50 km for 2 days (Sat. and Sun.)	44%	650	54
B. Weekday /weekend use	B-1: Active use	50 km for 4 days (Mon., Wed., Fri., and Sun.)	88%	11,300	200
	B-2: Suburban use	5 km for 4 days (Mon., Wed., Fri., and Sun.)	9%	-7,820	-23
C. Weekday use	C-1: Long-distance commuting	50 km for 5 days (weekdays)	100%	14,200	240
	C-2: Short-distance commuting	15 km for 5 days (weekdays)	33%	-2,010	18

3.1.2. Potential for Other Vehicles

Although this study focuses on added value for private passenger cars, onboard PV systems could also be installed on other vehicles, such as trucks. Fig. 3-1 shows the average distance driven by vehicles in Japan. While the average driving distance of passenger cars (for private use) is 11,797 km per vehicle per year, that of passenger cars (for commercial use) is 65,618 km per vehicle per year, light duty trucks 21,317 km per vehicle per year, and medium/heavy duty trucks 69,602 km per vehicle per year, respectively. This means such vehicles travel far further than private passenger cars. If onboard PV systems are installed with a suitable capacity for the distances covered and usage patterns of next generation versions of these vehicles, a further reduction in CO_2 emissions is expected.

As shown in Fig. 3-2, private passenger cars are responsible for around 50% of CO_2 emissions in the transport sector in Japan. The next largest are commercial and private trucks, which account for 35.2%. To reduce CO_2 emissions in the transport sector in Japan, installation of onboard PV systems on cargo vehicles could also be considered.

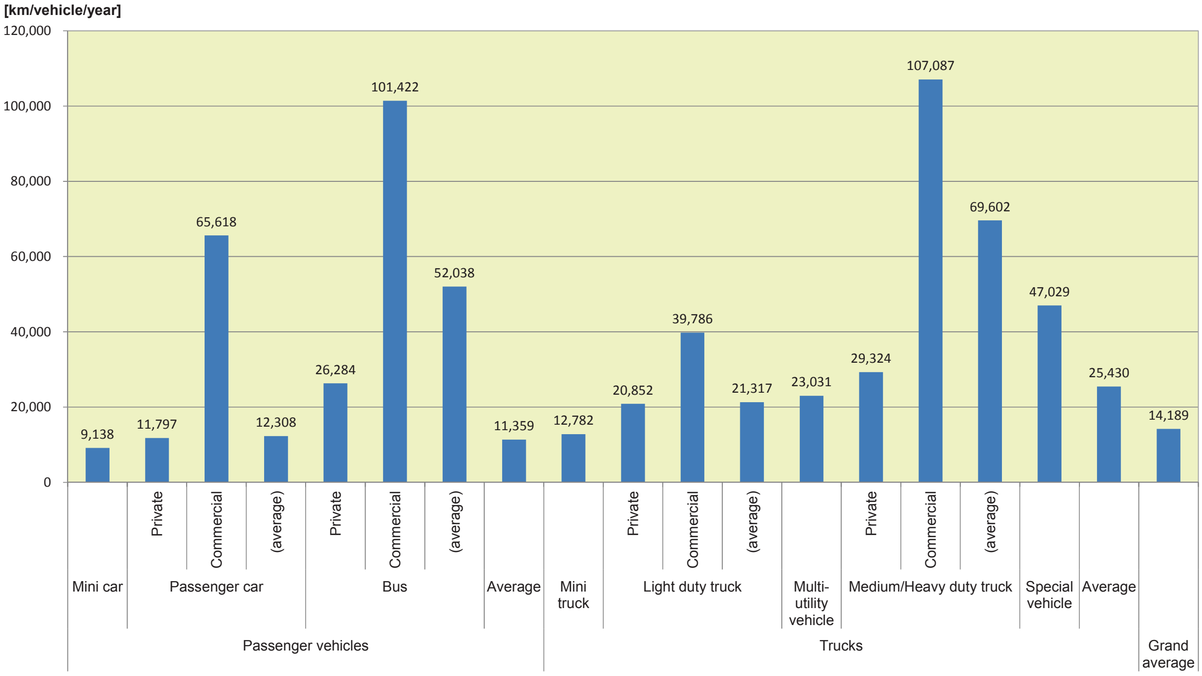


Fig. 3-1 Average annual driving distance by vehicle type in Japan[14]

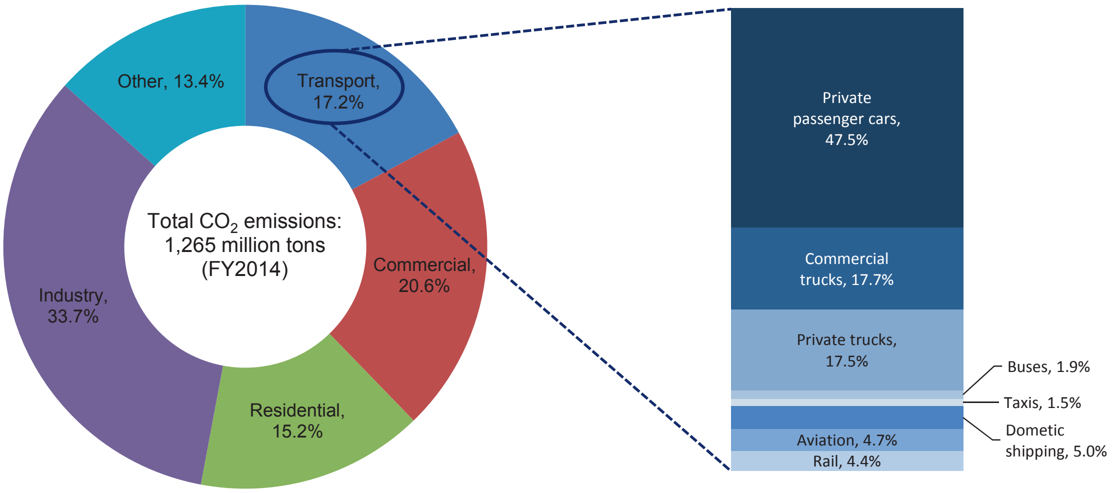


Fig. 3-2 Breakdown of CO_2 emissions in transport sector in Japan[15]

3.2. Issues Relating to Development and Adoption of PV-Powered Vehicles and Future Initiatives

3.2.1. Issues Relating to Development and Adoption

Examples of issues relating to the development and adoption of PV-powered vehicles are shown in Table 3-4. Issues relating to the realization and development include increasing the power supplied from PV systems, improving the electric fuel economy of PV-powered vehicles, and technical issues concerning reliability and safety. On the other hand, to introduce PV-powered vehicles into markets in other overseas regions, it is necessary to grasp the existing regulations and institutional framework of each country and recognize specific issues.

Proposed steps for promoting PV-powered vehicles internationally include, for example, regulatory and institutional proposals that can appeal to the life-cycle reduction in CO_2 emissions achieved by PV-powered vehicles, investigating market environments in each country, such as the driving modes of next generation vehicles, usage data, and solar radiation during parking, studying the specific added value of PV-powered vehicles in each country, and devising methods for evaluating the reduction in CO_2 emissions of PV-powered vehicles.

In addition, as PV-powered vehicles become widespread, new ways of utilizing electric power are expected to appear in the future. For issues following the widespread of PV-powered vehicles, such as how to make effective use of surplus power, it is important to address them in the social system as a whole. One possible example is the utilization as VPP (Virtual Power Plant), where PV-powered vehicles in Japan are regarded as a single large power source and are integrally controlled and incorporated into the domestic power grid. Use in the residential sector, such as V2H (Vehicle to Home) and use as a mobile power source during disasters are also being considered.

Although this study focuses on private passenger cars, high-efficiency PV cells also have other potential needs in markets in the transport sector. Exploring such potential markets should be also essential.

Table 3-4 Issues and things to be considered relating to the development and adoption of PV-powered vehicles

Issues			Things to be considered
Issues relating to realization and development	Technical issues	Increasing power supplied from PV system	Improving system efficiency
			Compatibility with curved surfaces (through flexibility, etc.)
			Suppressing fall in power due to partial shading
			Reducing degradation
		Improving electric fuel economy of PV-powered vehicles	Reducing weight of PV modules and system
			Improved energy efficiency for PV-powered vehicles
		Improving long-term reliability (quality) of PV-powered vehicles	Effect on long-term reliability of PV modules due to installation on next generation vehicles (partial shading, vibrations, etc.)
		Ensuring safety for PV-powered vehicles	Strength of PV modules
			Safety measures against collisions
			Preventing electric shock with DC power
		Other vehicle-side issues due to onboard PV system	Identifying issues when installing PV module on a vehicle
			Identifying issues for automobile systems due to installation of PV system
	Issues relating to existing regulations and institutional framework		Grasping regulatory state in each country when introducing PV-powered vehicles into markets
Issues relating to international adoption	Regulatory and institutional proposals		Regulatory and institutional proposals regarding safety, reliability, and quality
			Proposals regarding fuel economy regulations and exhaust gas regulations
	Understanding market environments		Gathering data on usage states to study added value in respective markets
			Research outlook of next generation vehicle market in each country
	Proposing methods of evaluating added value and benefits		Devising method for evaluating reduction in environmental impact
Adoption of PV-powered vehicles and establishment of an expected social system			Studying effective uses of surplus power
Development of new markets for high-efficiency PV cells			Exploring potential market needs in transport sector

3.2.2. Future Initiatives

We will continue to conduct studies related to PV-powered vehicles to investigate the issues listed above. In more detail, through NEDO's demonstration projects, we will gather the data required to grasp technical issues and market environments, while cooperating with other countries to make an international contribution and aim for standardization so that PV-powered vehicles become widely adopted and deployed worldwide.

4. Conclusion

(1) Significance and Role of PV-Powered Vehicles in Low-Carbon Society

PV-powered vehicles can boost the added value and expand the market of the PV industry, including high-efficiency PV cells. For the next generation vehicle industry, PV-powered vehicles can lead to further increased added value as an environmentally friendly technology.

In addition, should PV-powered vehicles succeed and become widely adopted, they are expected to make a large contribution to the reduction of greenhouse gas emissions in the global transport sector.

(2) Investigation of Added Value of PV-Powered Vehicles

The added value of PV-powered vehicles was analyzed in terms of the reduction in CO_2 emissions, economic benefit, and convenience (the number of charging cycles) when a 1 kW PV system was installed on next generation vehicles (EV, PHV, and HEV). The effect on society as a whole in reducing CO_2 emissions when PV-powered vehicles are widely adopted was also calculated.

Since the added value of PV-powered vehicles greatly varies with usage, six main usage patterns were analyzed. For long-distance weekend leisure-type users who drive 150 km per day on weekend (Saturday/Sunday), a reduction in CO_2 emissions of 240 kg-CO_2 per vehicle per year and an economic benefit of 14,200 JPY per vehicle per year were estimated for an EV. For these users, there is a fall in the number of charging cycles, but the vehicle does not become charging-free. For active users who drive 50 km per day in four days a week, a reduction in CO_2 emissions of 200 kg-CO_2 per vehicle per year and an economic benefit of 11,300 JPY per vehicle per year were estimated for an EV. In this usage pattern, the vehicle becomes charging-free, which is expected to make the vehicle much more convenient.

The reduction in CO_2 emissions in 2030 for Japan as a whole was estimated to be up to 2.27 million t-CO_2 per year, which accounts for 11% of the reduction in CO_2 emissions for passenger cars in Japan to be made by 2030.

(3) Issues Relating to Development and Adoption of PV-Powered Vehicles and Future Initiatives

The optimal capacity of a PV cell where 100% of the PV-generated power can be used and charging with grid power becomes unnecessary was estimated to be 1,270 W for long-distance weekend leisure users. When various users were considered, a PV cell capacity of around 1 kW is considered necessary for a PV-powered vehicle, and due to the limited area for installing PV of this capacity on a vehicle, high-efficiency PV cells with a conversion efficiency of 30% or higher are required.

Proposed steps for promoting PV-powered vehicles internationally include regulatory and institutional proposals that can appeal to the reduction in CO_2 emissions from a viewpoint of life-cycle achieved by PV-powered vehicles, investigating market environments in each country, such as the driving modes of next generation vehicles, usage data, and solar radiation during parking, studying the specific added value of PV-powered vehicles in each country, and devising methods for evaluating the reduction in CO_2 emissions of PV-powered vehicles.

In addition, as PV-powered vehicles become widespread, new ways of utilizing electric power are expected to appear in the future. For issues following the widespread of PV-powered vehicles, such as how to make effective use of surplus power, it will be important to address them in the social system as a whole.

Possible examples include an utilization as VPP (Virtual Power Plant) where PV-powered vehicles in Japan are regarded as a single large power source and are integrally controlled and incorporated into the domestic power grid and V2H (Vehicle to Home) in the residential sector.

PV-Powered Vehicle Strategy Committee

<List of committee members (as of 31 March 2017: the end of FY2016)>

Chair of committee	Masafumi Yamaguchi	Professor Emeritus, Senior Research Scholar, Research Center for Smart Energy Technology, Toyota Technological Institute, Japan
Committee member	Yuzuru Ueda	Junior Associate Professor, Department of Electrical Engineering, Faculty of Engineering, Tokyo University of Science, Japan
	Akinori Sato	Project Manager, Frontier Research Planning Dept., Frontier Research Center, TOYOTA MOTOR CORPORATION, Japan
	Yusuke Zushi	EV System laboratory, Nissan Research Center, Nissan Motor Co., Ltd., Japan
	Tatsuya Takamoto	Ph.D., Deputy General Manager, Head of New Engineering Development Unit, Energy Solutions BU, Sharp Corporation, Japan
	Toshio Hirota	Ph.D., Environmental Research Institute, Waseda University, Japan
Observer	Masaomi Koyama	Deputy Director, New and Renewable Energy Division, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, Japan
Secretariat	Hiroyuki Yamada	Ph.D., Director, Solar Energy Systems, New Energy Technology Development, New Energy and Industrial Technology Development Organization, Japan
	Mami Hasegawa	Chief Officer, Solar Energy Systems, New Energy Technology Development, New Energy and Industrial Technology Development Organization, Japan
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	Shouhei Namikawa	Consultant, Environment and Energy Division 2, Mizuho Information & Research Institute, Inc., Japan
	Takafumi Sato	Consultant, Environment and Energy Division 2, Mizuho Information & Research Institute, Inc., Japan

<Schedule of committee meeting>

1st meeting : 11 April 2016
2nd meeting : 16 May 2016
3rd meeting : 13 June 2016
4th meeting : 8 July 2016
5th meeting : 2 September 2016
6th meeting : 28 February 2017

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January 2018