Chapter 4

Climate Policy in Transportation Sector: Role of Carbon Pricing

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Abstract This chapter focuses on climate countermeasures in the Japanese transport sector. We introduce the Japanese complexed automobile tax system and then calculate the Japanese effective carbon rate (ECR) on automobiles. In addition to the discussion of the ECR, this chapter offers a simple examination of the efficiency of electric vehicles (EVs) from the viewpoint of cost-benefit because it is expected that EVs will become the most popular eco-friendly vehicle in the future. Two remarks are found in our analysis. First, although the carbon tax rate on fuel consumption is small in Japan, compared to the European countries, the ECR is rather high. For further improvement of climate policy, the Japanese government should shift its attention to vehicle usage from vehicle purchase and possession. Second, under the basic assumption (i.e., representative owners do not recharge their EVs at home but at outdoor fast chargers), the diffusion of EVs is not an efficient measure for reducing GHG emissions. If owners recharge their EVs at home once of every two charges, the net benefit becomes positive. Therefore, the opportunity cost of waiting for recharges is a key factor in whether EVs can play a role in mitigating climate change.

Keywords Automobiles · Carbon tax · Effective carbon rate · Life cycle assessment · Electric vehicles · Fast chargers

1 Introduction

Automobiles are one of the most important sources of greenhouse gases (GHG) emissions. In Japan, the amount of total GHG emissions was 1.19 billion t-CO₂ in 2017 (Ministry of the Environment, 2019). Of that amount, 0.21 billion t-CO₂ (i.e., 17.9%) was attributable to the transport sector. Automobiles, including passenger vehicles and trucks, accounted for 86.2% of the GHG emissions from the transport

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Fig. 1 Trends in GHG emissions and indicators related to vehicles in Japan (The data of the GHG emissions (the top-left panel), number of vehicles (the top-right panel), annual mileage (the bottom-left panel) and fuel efficiency (the bottom-right panel) are obtained from the websites of the Greenhouse Gas Inventory Office of Japan (<http://www-gio.nies.go.jp/aboutghg/nir/nir-e.html>), the Automobile Inspection and Registration Information Association (<https://www.airia.or.jp/publish/statistics/trend.html>), the Survey on Motor Vehicle Transport (<https://www.mlit.go.jp/k-toukei/jidousya.html>) and the Ministry of Land, Infrastructure, Transport and Tourism (<https://www.mlit.go.jp/common/001178377.pdf>), respectively (accessed on December 10, 2019).)

sector.¹ Therefore, 0.18 billion t-CO₂ (15.4%) of the total GHG emissions were generated by automobiles. Although automobiles emit not only the GHG but also air pollutants, this chapter focuses on the GHG only.

Although automobiles are responsible for a large share of GHG emissions, the total amount of emissions has been continuously decreasing since approximately 2000. The top-left panel in Fig. 1 shows the trends in GHG emissions from passenger vehicles and trucks. The emissions peaked in 2002 and 1995 for passenger vehicles and trucks, respectively, and then started decreasing.

What led to the decreased in emissions? There are three potential drivers of the reductions: the total number of vehicles, annual mileage per vehicle and fuel efficiency. The first, the total number of passenger vehicles and trucks (including buses), is presented in the top-right panel in Fig. 1. The numbers of passenger vehicles and trucks have been gradually increasing and decreasing, respectively. The reason why

¹Refer to the following website of the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLITT): https://www.mlit.go.jp/sogoseisaku/environment/sosei_environment_tk_000007.html (accessed on December 10, 2019).

the total number of passenger vehicles has increased is the popularity of hybrid vehicles such as the Prius.² In tandem with the increase in hybrid vehicles, the number of traditional gasoline and diesel passenger vehicles has been decreasing, suggesting that passenger vehicles have been shifting from gasoline and diesel vehicles to eco-friendly hybrid vehicles. Meanwhile, the total number of trucks has continuously decreased since 1990.

The kilometers travelled by passenger vehicles and trucks are shown in the bottom-left panel in Fig. 1. The annual mileage for gasoline passenger vehicles is likely to decrease over time. The decrease may come from increase of aging population because older drivers voluntarily limit vehicle usage (Baldock et al. 2006). For diesel trucks, the annual mileage increased until 2008 and then started decreasing. It is thought that this trend may be correlated with Japanese economic conditions. The economic boom lasted until approximately 2009, when the financial crisis happened due to the collapse of Lehman Brothers. After that, the recession started.

The Ministry of Land, Infrastructure, Transport and Tourism shows that the average fuel efficiency of gasoline passenger vehicles is improving over time, suggesting that this improvement has helped to reduce GHG emissions (see the bottom-right panel in Fig. 1). For example, average fuel efficiency in 2015 increased to 21.6 km/liter compared with 11.1 km/liter, 12.2 km/liter, 13.6 km/liter and 16.5 km/liter in 1995, 2000, 2005 and 2010, respectively. Therefore, in the last 30 years, fuel efficiency has improved approximately twice over. This consistent increase is mainly due to the diffusion of hybrid vehicles.

GHG emissions from vehicles reached a peak in 2001 (see Fig. 1). Although the total amount of emissions has continuously decreased over time, 0.18 billion t-CO₂ in 2017 was still caused by vehicles. To cost-efficiently reduce GHG emissions from vehicles, economic instruments such as emission trading schemes or Pigouvian taxes are the best countermeasures (Kolstad 2010).

For automobiles, it is cost-efficient to impose a Pigouvian carbon tax on gasoline and diesel according to their CO₂ coefficients. In 1990, the first carbon tax in the world was implemented in Finland. Then, Sweden introduced a similar tax in 1991. Of course, the two taxes cover gasoline consumption. The World Bank reports that there were 28 countries and regions³ where carbon taxes had already been implemented as a carbon pricing initiative by 2019.⁴ In Japan, a carbon tax was introduced in October 2012. The initial tax rates were 250 yen (US\$2.3)⁵ per kiloliter, 260 yen (US\$ 2.4) per ton and 220 yen (US\$2) per ton for petroleum, liquefied natural gas (LNG) and coal, respectively. The government had originally planned to raise the tax rates. Eventually, in 2016, these rates increased by approximately triple, that is, to 760 yen (US\$6.9) per kiloliter, 780 yen (US\$7.1) per ton and 670 yen (US\$6.1) per

²The Prius was released in 1997 by Toyota as first hybrid vehicle in the world.

³Alberta in Canada will abolish its carbon tax in 2020.

⁴Refer to the following website of the World Bank: <https://carbonpricingdashboard.worldbank.org/> (accessed on December 10, 2019).

⁵US\$1 roughly equals to 110 yen.

ton. Automobiles are indirectly affected by this carbon tax because the tax covers petroleum.

The current Japanese carbon tax rates are equivalent to 289 yen (US\$2.6) per t-CO₂.⁶ Viewing the carbon tax rates among 28 countries and regions, the highest rate is US\$121.3 per t-CO₂ in Sweden. The next highest rate is US\$96.6 per t-CO₂ in Liechtenstein and Switzerland. Therefore, the carbon tax rate in Japan is relatively low compared with such countries. Another efficient economic instrument is an emission trading scheme (ETS); the carbon prices in the EU ETS and Korea ETS are US\$32.5 and US\$24.2 per t-CO₂ in 2019, respectively, whereas the price in the Japanese Tokyo ETS⁷ is only US\$6.0. In addition, firms located outside of Tokyo are not affected by the Tokyo ETS. We observe that the carbon price of the ETS in Japan is also low.

To efficiently reduce GHG emissions and achieve a balance between economic development and implementation of countermeasures against climate change, it is necessary to set appropriate carbon prices using economic instruments such as a carbon tax or an ETS. The efficient carbon price should be set to be equal to the social cost of carbon (SCC). Although many studies have estimated the SCC, there are large differences among them. In a recent study, Wang et al. (2019) reviewed 578 estimates of the SCC from 58 studies (the range is between US\$-13.38 and US\$2386.91 per t-CO₂) and concluded that the SCC is US\$54.7 per t-CO₂, on average. As mentioned above, the Japanese total carbon price is US\$8.6, which sums the US\$2.6 for the carbon tax and US\$6.0 for the Tokyo ETS. The value is obviously lower than the SCC of Wang et al. (2019). Therefore, it may appear that the Japanese government should raise its carbon price to mitigate climate change.

However, several types of taxes besides carbon taxes and ETS costs are already imposed on most goods. For example, many counties impose a value-added tax (VAT) as a consumption tax, and a gasoline tax is often levied on the usage of vehicles. Although the purpose of such taxes is not to prevent climate change but to secure governmental financial resources, such taxes indirectly play the same role as a carbon tax or ETS. The expanded carbon price, which is the sum of carbon taxes, ETS costs and such indirect taxes, is called the effective carbon rate (ECR) (OECD 2016).

In Japan, the ECR for automobiles is complicated because the automobile tax system is not simple. Therefore, this chapter will introduce the Japanese automobile tax system and then calculate the Japanese ECR on automobiles. In addition to the discussion of the ECR, this chapter offers a simple examination of the efficiency of electric vehicles (EVs) because it is expected that EVs will become the most popular eco-friendly vehicle in the future. The IEA (2019) reports that EVs are developing at a rapid pace. For example, the number of EVs was more than 5.1 million in 2018, compared to 3 million in 2017. The report concludes that the market share of EVs

⁶Refer to the following website of the Japanese Ministry of the Environment: <https://www.env.go.jp/policy/tax/about.html> (accessed on December 10, 2019).

⁷The Tokyo ETS does not cover automobiles but covers facilities including office buildings and industrial plants.

Table 1 Automobile tax system in Japan

Behavior	Tax	Frequency	Note	Rate (%)
Purchase	Vehicle acquisition tax ^a	Only once		0–3
	VAT on vehicle purchase	Only once		10
Possession	Vehicle tax	Every year	For vehicle with displacement over 661	
	Light vehicle tax	Every year	For vehicle with displacement under 660	
	Vehicle weight tax	Once every two years		
Usage	Gasoline tax	Each time	For gasoline vehicle	
	Diesel oil tax	Each time	For diesel vehicle	
	VAT on fuel purchase	Each time		
	Carbon tax	Each time		
	Petroleum coal tax	Each time		

^aThe vehicle acquisition tax was greatly revised on October 2019. Before the revision, the tax rate was fixed at 3%

will be 30% by 2030. In addition, Japan Post Holdings stated in a press release that it will introduce 1200 EVs for use in delivery service by 2020, implying that 30% of delivery vehicles in Tokyo will be EVs.⁸

2 ECR on Automobiles in Japan

2.1 Automobile Tax System

Before calculating the ECR in Japan, this section provides an overview of the automobile tax system. A summary of the tax system is shown in Table 1. In October 2019, the tax system for vehicles drastically changed. Briefly, the tax rate for eco-friendly vehicles decreased.

The tax system for vehicles in Japan consists of taxes on three behaviors: purchase, possession and usage. Suppose that people buy a new or an old vehicle and use it. They must pay various taxes in addition to the vehicle and fuel costs. First, they

⁸Refer to the following newspaper website of Asahi Shimbun: <https://www.asahi.com/articles/ASMCF4RRPMCFLFA016.html> (accessed on December 10, 2019).

must pay two types of taxes on vehicle purchase: *vehicle acquisition tax* and VAT. These taxes are imposed only once. The *vehicle acquisition tax* rate is set to 0%, 1%, 2% or 3%, according to vehicle environmental performance characteristics such as fuel efficiency. The tax rate for EVs is set at the lowest rate of 0% because their environmental performance is better than those of conventional vehicles. Vehicles with low performance face higher tax rates. The VAT rate was fixed at 10% after October 2019.⁹ When a person purchases a new vehicle at a price of 1 million yen (US\$9091) and the *vehicle acquisition tax* rate is 2%, (s)he needs to pay 20,000 yen (US\$182) and 100,000 yen (US\$909) for the *vehicle acquisition tax* and VAT, respectively.

The second type of tax is on vehicle possession. Vehicle owners have an obligation to have a legal inspection of their vehicles carried out once every two years to use them on the road. If vehicles do not pass inspection, they cannot be used on the road. Owners must pay *vehicle taxes* or *light vehicle taxes* every year for their vehicles to be considered eligible for inspection. If they forget to make the payment, the vehicles cannot be inspected, meaning that they cannot travel on the road. Which tax is applied depends on the displacement of the vehicle. When the displacement is more than 661 cc, the *vehicle tax* is applied. Otherwise, the *light vehicle tax* is applied. Even when vehicle owners do not use their vehicle at all, they are required to pay this tax because it is on vehicle possession. The greater the vehicle displacement is, the higher the annual amount of the *vehicle tax*.¹⁰ The tax amount increases for every 500 cc of displacement. For example, the tax amount for passenger vehicles with a displacement of 1000 cc is 25,000 yen (US\$227) a year, whereas the amount for passenger vehicles with a displacement of 3000 cc is 50,000 yen (US\$455) a year. Different from the *vehicle tax*, the amount of the *light vehicle tax* is fixed at 7200 yen (US\$65) a year.¹¹

In addition to the *vehicle tax* or *light vehicle tax*, all vehicle owners must pay the *vehicle weight tax* when a legal inspection is carried out. The first inspection occurs 3 years after a new vehicle is purchased, and then the following inspections occur every 2 years. Therefore, vehicles will undergo inspections and owners will pay the *vehicle weight tax* at 3, 5, 7 and so on years thereafter. As the name suggests, the tax rate depends on the vehicle weight. The greater the vehicle weight, the higher the tax rate is. For example, the standard tax amounts for passenger vehicles with weights of 1000 and 2000 kg are set to 16,400 yen (US\$149) and 32,800 yen (US\$298), respectively. In addition to the weight, the tax rates change according to the environmental performance and vehicle age. For the case of a passenger vehicle with a weight of 1000 kg and high environmental performance, the tax amount decreases from 16,400 yen (US\$149) to 10,000 yen (US\$91). In contrast, for a passenger vehicle with the same weight and age of 18 (i.e., a very old vehicle), the tax amount increases from

⁹The VAT rate was 8% before September 2019.

¹⁰The *vehicle tax* amount varies across vehicle type and purpose of use. The tax amount shown here is for passenger vehicles for personal use.

¹¹The *light vehicle tax* amount also depends on vehicle type and purpose of use. The tax amount shown here is for passenger vehicles for personal use.

Fig. 2 Tax revenues from each tax related to automobiles in 2018

16,400 yen (US\$149) to 25,200 yen (US\$229). The *vehicle tax* and *light vehicle tax* are local tax, whereas the *vehicle weight tax* is a national tax.

Gasoline or diesel is necessary to use vehicles. The third type of tax is on fuel consumption. The retail price for gasoline includes the *gasoline tax*, *petroleum coal tax* and *carbon tax*. In addition to these three taxes, vehicle users pay VAT when purchasing gasoline, meaning that they pay 4 taxes when using gasoline vehicles. For diesel vehicles, users pay *diesel oil tax* instead of *gasoline tax*. The *gasoline tax* and *diesel tax* rates are 53.8 yen (US\$0.49) and 32.1 yen (US\$0.29) per liter, respectively. The *petroleum coal tax* and *carbon tax* are imposed on all oil and coal products, including gasoline and diesel oil. The *petroleum coal tax* is 2.04 yen (US\$0.02) per liter, and the *carbon tax* is 0.74 yen (US\$0.01) per liter, implying that these tax rates are relatively smaller than the *gasoline tax* and *diesel oil tax* rates. In particular, the carbon tax rate is much smaller than the other conventional fuel taxes.

Figure 2 presents the revenue from each tax in 2018.¹² The tax revenues of the *carbon tax* and *petroleum coal tax* are calculated from the tax rates and consumption data. The data are obtained from the Survey on Motor Vehicle Fuel Consumption. The other revenues are quoted from the website of the Japan Automobile Manufacturers Association.¹³ The total amount of tax revenue was approximately 8829 billion yen (US\$80.3 billion). The revenue from the carbon tax was only 58 billion yen (US\$0.52 billion), which indicates that the *carbon tax* is of less importance from the viewpoint

¹²For the tax revenues from the *petroleum coal tax* and *carbon tax*, the 2017 values are used.

¹³http://www.jama.or.jp/tax/outline/image_01.html (accessed on December 10, 2019).

of tax revenue. The most important revenue source is the *gasoline tax*, followed by the VAT on vehicle purchase and the *vehicle tax*.

2.2 Actual ECR After Consideration of the Tax System

The described 10 types of taxes are levied on vehicle possession and usage in Japan. In this subsection, we simulate and discuss how much GHG emissions vehicle owners generate and pay taxes on from the perspective of a life cycle assessment. For the simulation, we assume that Japanese drivers are average passenger vehicle owners.

Each car owner drove 6300 km in 2018 (Sony Assurance, 2018). The average fuel economy of gasoline passenger vehicles is 21.9 km per liter (MLITT 2017). Therefore, the average car consumes 287.7 L of gasoline per year. Using the CO₂ emission coefficient of 2.348 kg-CO₂ per gasoline liter presented by the IEA (2011) yields an equivalence of approximately 676 kg-CO₂ per year. The Automobile Inspection & Registration Information Association (AIRIA) reports that the average number of years of passenger vehicle usage in 2018 was 13.24.¹⁴ Therefore, the lifetime total amount of GHG emissions is approximately 8943 kg-CO₂ (=676 kg-CO₂ per year × 13.24 years). With a social discount rate of 4% (MLITT 2018) on the total amount of the emission, the present discounted emission is 7112 kg-CO₂. After 13.24 years, we assume that the owners scrap their vehicles.

The average gasoline retail price in 2018, 149.9 yen per liter, was obtained from the Survey on Petroleum Product Price by the Agency for National Resources and Energy. The average owner annually spends approximately 43 thousand yen on gasoline. Over the long term, the total amount of gasoline consumption costs approximately 571 thousand yen.

The average vehicle price is assumed to be 2525 thousand yen (US\$23.0 thousand), which is the average value of the prices of the Note (2131 thousand yen; US\$19.4 thousand), Aqua (2314 thousand yen; US\$21.0 thousand) and Prius (3132 thousand yen; US\$28.5 thousand) car models. These were the top three best selling cars in 2018.¹⁵ In the same manner, the weight and displacement of the average vehicle are set to 1212 kg and 1497 cc, which are the averages of the weights and displacements, respectively, of these three described vehicles. The characteristics of the assumed average vehicle are shown in Table 2.

Hereafter, we calculate how much owners of the average vehicle pay for the various taxes over the 13.24-year life cycle. We ignore scrapping cost in the calculation. The calculation results are presented in Table 3. The rows in the table denote the vehicle age, so row 14 indicates the final year, when vehicles are scrapped. The owners,

¹⁴<https://www.airia.or.jp/publish/file/r5c6pv000000m20m-att/r5c6pv000000m211.pdf> (accessed on December 10, 2019).

¹⁵In 2018, the best-selling vehicle was the Note, produced by Nissan; 136,324 vehicles were sold. The next best sellers were the Aqua and Prius, manufactured by Toyota. The sales volumes of the Aqua and Prius were 126,561 and 115,462, respectively.

Table 2 Features of the assumed average vehicle

Terms	Value	Unit	References
Annual mileage	6300	km/year	Sony Assurance (2018)
Fuel efficiency	21.9	km/litter	MLITT (2017)
CO ₂ coefficient	2.348	kg-CO ₂ /litter	IEA (2011)
Vehicle price	2525	thousand yen	Average retail price among Note, Aqua and Prius
Vehicle weight	1212	kg	Average weight among Note, Aqua and Prius
Vehicle displacement	1497	cc	Average displacement among Note, Aqua and Prius
Years of vehicle usage	13.24	years	AIRIA website
Gasoline price	149.9	yen/litter	The survey on petroleum product price

Table 3 Amount of tax payments until vehicle scrapping (unit: thousand yen)

Year	Purchase		Possession		Usage			
	Vehicle acquisition tax	VAT on vehicle purchase	Vehicle tax	Vehicle weight tax	Gasoline tax	VAT on fuel purchase	Carbon tax	Petroleum coal tax
1	25.3	252.5	34.5	11.2	15.5	4.3	0.2	0.6
2	0.0	0.0	33.2	0.0	14.9	4.1	0.2	0.6
3	0.0	0.0	31.9	0.0	14.3	4.0	0.2	0.5
4	0.0	0.0	30.7	13.3	13.8	3.8	0.2	0.5
5	0.0	0.0	29.5	0.0	13.2	3.7	0.2	0.5
6	0.0	0.0	28.4	12.3	12.7	3.5	0.2	0.5
7	0.0	0.0	27.3	0.0	12.2	3.4	0.2	0.5
8	0.0	0.0	26.2	11.4	11.8	3.3	0.2	0.4
9	0.0	0.0	25.2	0.0	11.3	3.2	0.2	0.4
10	0.0	0.0	24.2	10.5	10.9	3.0	0.2	0.4
11	0.0	0.0	23.3	0.0	10.5	2.9	0.1	0.4
12	0.0	0.0	22.4	9.7	10.1	2.8	0.1	0.4
13	0.0	0.0	21.5	0.0	9.7	2.7	0.1	0.4
14	0.0	0.0	6.9	3.0	2.2	0.6	0.0	0.1
Total	25.3	252.5	365.2	71.5	163.0	45.4	2.3	6.2

Note Tax rates of the *vehicle acquisition tax*, *vehicle tax* and *vehicle weight tax* are discounted for designated eco-friendly vehicles such as plug-in hybrid vehicles and EVs. The tax rates for eco-friendly vehicles are applied for the calculation

therefore, pay only a quarter of each tax in the final year because they hold their vehicles for only 0.24 years (approximately 3 months). With a social discount rate of 4%, the present discounted value of the tax payment is 931.4 thousand yen in total. Considering the total discounted emission volume described above, the ECR from the viewpoint of life cycle assessment is 131.0 thousand yen (US\$1.19 thousand) per t-CO₂, implying that the ECR in Japan is considerably higher than the SCC of US\$54.7 per t-CO₂ determined by Wang et al. (2019). It is concluded that the Japanese government should reduce the tax rate on automobiles because the ECR is too high.

Of the total payment, 365.2 thousand yen (US\$3.32 thousand), the highest tax payment, is attributable to the *vehicle tax*. The tax with next highest payment is the *VAT* on vehicle purchase and then the *gasoline tax*. When aggregating tax payments by behavior, the tax payments for purchase, possession and usage are 277.8, 436.7 and 216.8 thousand yen (US\$2.07 thousand, US\$3.97 thousand and US\$1.97 thousand), respectively. Therefore, the tax payment for usage is lowest, implying that the Japanese automobile tax system emphasizes taxes on vehicle purchase and possession.

Assuming that the average vehicle features are as shown in Table 2, we calculate the long-term ECR as the total tax payment divided by GHG emissions. If vehicles are assumed to be fuel inefficient, *ceteris paribus*, the ECR decreases because the denominator becomes larger. If vehicles are assumed to be more expensive, the ECR increases because the numerator becomes larger. These changes are due to the features of the Japanese automobile tax system, where the main tax target is not fuel consumption but vehicle purchase and possession.

GHG emission is not generated from vehicle purchase and possession but usage (i.e., fuel combustion). Therefore, a Pigouvian carbon tax should be imposed on vehicle usage to attain cost efficiency. According to economic theory, the extent of the Pigouvian carbon tax should equal the SCC. Therefore, the Japanese government should shift its attention in the automobile tax system from purchase and possession to usage. At the same time, it should reduce the tax rates on vehicle usage to cost-effectively reduce GHG emissions.

Table 4 shows the ECR for an average vehicle. In general, the ECR is calculated by summing taxes on fuel consumption only (OECD 2018), that is, the 4 types of taxes on usage. In this case, the ECR is 30.5 thousand yen (US\$ 277) per t-CO₂. The OECD (2016) reports that the Japanese ECR on road vehicles in 2012 was approximately 22.6 thousand yen (US\$205) per t-CO₂. Considering that the estimated ECR depends on vehicle characteristics (as in Table 2), our calculated ECR is not greatly different from that of the OECD (2016). Additionally, the difference may come from the

Table 4 The ECR for an average vehicle

	Purchase	Possession	Usage	Total
Tax payment (thousand yen)	277.8	436.7	216.8	931.4
Tax payment/GHG emissions (thousand yen/ t-CO ₂)	39.1	61.4	30.5	131.0

different benchmark years. The benchmark years of this chapter and the OECD (2016) report are 2018 and 2012, respectively.

The OECD (2016) also shows the ECRs for 40 countries, including Japan. The highest ECR, 33.7 thousand yen (US\$307) per t-CO₂, is implemented in the UK. Of the 40 countries, Japan has the 14th highest ECR on road vehicles. That is, although the carbon prices of the *carbon tax* and the Tokyo ETS in Japan are smaller than those in other countries, it is confirmed that the ECR is sufficiently high compared to the SCC.

3 Cost-Benefit of EVs in Japan

3.1 Construction Cost for Fast Chargers

After the consideration of the ECR on automobiles in Japan in the previous section, this section conducts a cost-benefit analysis of the diffusion of EVs. Different from previous studies examining the effects of EVs, this chapter explicitly considers the recharging time of EVs, which is a social loss, similar to congestion. The basic concept of the analysis follows the method of Ito and Managi (2015). In this cost-benefit analysis, we assume that all vehicles in Japan are substituted by EVs, that is, that there are no conventional gasoline or diesel vehicles. The AIRIA shows that there are approximately 62.1 million vehicles in Japan.¹⁶ Therefore, our analysis assumes that there are same number of EVs.

Similar to refuelling stations for conventional gasoline vehicles, EVs require fast chargers outside of homes. Of course, frequently charging EVs at home may eliminate the demand for fast charging them elsewhere. However, when EVs travel long distances, fast chargers are always required. Therefore, considering the diffusion of EVs, many new fast chargers must be constructed.

We calculate the required number of fast chargers and their construction costs. The required number of fast chargers can be obtained from the total yearly electric power consumption divided by the yearly electric power supply per charger [Eq. (1)]. In the equation, the term in parentheses denotes the unit. The value of the yearly electric power supply per charger is set to approximately 140,160 kWh/unit/year, obtained from Mitsubishi UFJ Research and Consulting (2014). The report shows that the fast charger takes 30 min to charge 8 kWh. In other words, the charger takes one year to charge 140,160 kWh.

The total yearly electric power consumption is calculated by multiplying the total number of EVs (i.e., 62.1 million vehicles) and the required electric power consumption per EV [Eq. (2)]. On the assumption that drivers' behaviors are not changed by the use of EVs, the required electric power consumption per EV is obtained from the annual mileage (i.e., 6300 km in Table 2) divided by the EV

¹⁶<https://www.airia.or.jp/publish/statistics/ub83e100000000wo-att/01.pdf> (accessed on December 10, 2019).

driving distance per kWh [Eq. (3)]. We use approximately 9.3 km/kWh as the driving distance of the EV, which is equal to the performance of the Leaf model produced by Nissan.¹⁷ According to the three equations, the required number of fast chargers is 299,069. In the calculation, we assume that all EV owners do not recharge their EVs at home but at fast chargers outdoors. Therefore, the required number can be regarded as the maximum.

$$\begin{aligned} & \text{Number of fast chargers(units)} \\ &= \frac{\text{Total yearly electric power consumption(kWh/year)}}{\text{Yearly electric power supply per charger}\left(\frac{\text{kWh}}{\text{unit}\cdot\text{year}}\right)} \end{aligned} \quad (1)$$

$$\begin{aligned} & \text{Total yearly electric power consumption(kWh/year)} \\ &= \text{Total number of EVs(vehicles)} \\ & \times \text{Required electric power consumption per EV}\left(\frac{\text{kWh}}{\text{vehicle}\cdot\text{year}}\right) \end{aligned} \quad (2)$$

$$\begin{aligned} & \text{Required electric power consumption per EV}\left(\frac{\text{kWh}}{\text{vehicle}\cdot\text{year}}\right) \\ &= \frac{\text{Annual mileage}\left(\frac{\text{km}}{\text{vehicle}\cdot\text{year}}\right)}{\text{driving distance of EV per kWh(km/kWh)}} \end{aligned} \quad (3)$$

The construction cost of the fast charger is set to 2.25 million yen (US\$20.5 thousand) (Mitsubishi UFJ Research and Consulting, 2014). The statutory useful life for a fast charger is 8 years.¹⁸ Therefore, ignoring a discount rate, the annual cost per charger is approximately 281 thousand yen (US\$2.26 thousand). The total annual cost for constructing fast chargers is 84.1 billion yen per year (US\$0.76 billion). The values and data sources in the calculation are shown in Table 5.

3.2 GHG Emission Reduction

As mentioned earlier, the amount of GHG emissions from automobiles is 0.18 billion t-CO₂. In the case that all conventional gasoline and diesel vehicles are replaced with EVs, the amount of GHG emissions from fuel consumption becomes zero. Therefore, the direct emission reduction effect of EVs is 0.18 billion t-CO₂.

On the other hand, EVs need electric power. The total yearly electric power consumption of EVs is already calculated in Eq. (2): approximately 42.9 GWh per

¹⁷The Leaf with a 30 kWh battery can travel 280 km on a full charge; <http://history.nissan.co.jp/LEAF/ZE0/1211/charge.html> (accessed on December 10, 2019).

¹⁸Refer to the Next Generation Vehicle Promotion Center website: http://www.cev-pc.or.jp/hojo/pdf/h31/H23-H24_kouhukitei_saisoku.pdf (accessed on December 10, 2019).

Table 5 Data sources for calculating construction cost

Term	Value	Unit	Source
Yearly electric power supply per charger	140,160	kWh/unit/year	Mitsubishi UFJ Research and Consulting (2014)
Total number of EVs	62.1	million vehicles	AIRIA website
Annual mileage	6200	km/year	Sony Assurance (2018)
Driving distance of EV per kWh	9.3	km/kWh	Nissan website
Construction cost of fast charger	2.25	million yen/unit	Mitsubishi UFJ Research and Consulting (2014)
Statutory useful life for fast charger	8	years	Next Generation Vehicle Promotion Center website

year. Therefore, that amount of electric power must be newly generated for the use of EVs. Here, the additional electric power is assumed to be generated by thermal power generation (i.e., coal, oil and LNG). Viewing the breakdown of thermal power generation, coal, oil and LNG account for 40.4%, 10.8% and 48.8%, respectively (Agency for Natural Resources and Energy 2018). Therefore, when the power generation amount is apportioned at these rates, 16.9, 4.5 and 20.5 GWh are generated by coal, oil and LNG thermal generation. Since the CO₂ coefficients for each type of power generation are 943, 738 and 599 gram-CO₂ per kWh, respectively (Imamura et al. 2016), the additional annual total amount of GHG emissions is 31.5 million t-CO₂.

Therefore, the amount of net GHG emission reduction is approximately 0.15 billion t-CO₂ because the reduction in emissions from replacement of other vehicles with EVs exceeds the increase in emissions from the related power generation. When the reduction is converted into monetary value with the SCC at 6017 yen (US\$54.7) per t-CO₂ in line with Wang et al. (2019), the annual benefit of reducing GHG emissions from diffusion of EVs is approximately 916.4 billion yen (US\$ 8.33 billion).

3.3 Opportunity Cost of Recharging Time

The EV owner must wait for the vehicle to recharge at the charging station. They may do something to work during the recharging time (e.g., input work using a laptop). However, for simplicity, we ignore this possibility. That is, we consider the recharge wait time to be an opportunity cost. Although the charging time has become shorter, Mitsubishi UFJ Research and Consulting (2014) reports that it takes 30 min to fully recharge an EV.

EV owners annually drive 6300 km, and an EV can travel 280 km on a single charge (see the previous Sect. 3.2). Owners thus recharge their EVs at charging stations 22.5 times a year. The time value of driving is presented in MLITT (2018)

at 39.6 yen per minute. Following Eq. (4), the annual opportunity cost per EV is 26,730 yen (US\$243).

$$\begin{aligned}
 \text{Opportunity cost for EV} & \left(\frac{\text{yen}}{\text{vehicle}} \right) = \text{recharging time} \left(\frac{\text{minute}}{\text{time}} \right) \\
 & \times \text{number of recharges}(\text{time}) \\
 & \times \text{time value of driving} \left(\frac{\text{yen}}{\text{vehicle} \cdot \text{minute}} \right)
 \end{aligned} \tag{4}$$

When using conventional gasoline vehicles, owners must refill fuel at refuelling stations. The Fire and Disaster Management Agency reports that the refuelling amount is on average 30.6 L.¹⁹ The refuelling speed of the refuelling machine is legally set to between 30 and 35 L per minute by the Fire Service Act. Using the average speed of 32.5 L per minute and the average refuelling amount, we can calculate the refuelling time for each refuel as approximately 0.94 min.

Since gasoline vehicle owners consume 287.7 L of gasoline per year, calculated by the annual mileage (i.e., 6300 km) divided by the fuel efficiency (i.e., 21.9 km per liter), they refuel their vehicles approximately 9.4 times for a year (=287.7 L per year/ 30.6 L). Therefore, the opportunity cost for conventional gasoline vehicles is approximately 350 yen (US\$3.2), calculated as in Eq. (5). The opportunity cost of refuelling conventional vehicles is quite small compared to that of recharging EVs.

$$\begin{aligned}
 \text{Opportunity cost for conventional vehicles} & \left(\frac{\text{yen}}{\text{vehicle}} \right) \\
 = \text{refuelling time} & \left(\frac{\text{minute}}{\text{time}} \right) \\
 & \times \text{number of refuels}(\text{time}) \\
 & \times \text{time value of driving} \left(\frac{\text{yen}}{\text{vehicle} \cdot \text{minute}} \right)
 \end{aligned} \tag{5}$$

The net opportunity cost of replacing conventional vehicles with EVs is 26,379 yen (US\$239.8). Considering that the number of vehicles is 62.1 million, the total opportunity cost is 1638.2 billion yen (US\$14.9 billion). The data sources for calculating the costs are described in Table 6.

3.4 Total Net Benefit of EVs

Three components of EV net benefit have been calculated: the construction cost, the benefit from the GHG reduction and the net opportunity cost. The amounts of those components are annually 84.1 billion yen, 916.4 billion yen and 1638.2 billion

¹⁹Refer to the Fire and Disaster Management Agency website: <https://www8.cao.go.jp/kisei-kai kaku/kaigi/meeting/2013/wg/ene/130508/item2-2.pdf> (accessed on December 10, 2019).

Table 6 Data sources for calculating opportunity costs

Term	Value	Unit	Source
Recharging time	30	minute	Mitsubishi UFJ Research and Consulting (2014)
Annual mileage	6200	km/year	Sony Assurance (2018)
Travel distance on a single charge	280	km	Leaf with 30kWh battery
Time value of driving	39.6	yen/minute	MLITT (2018)
Refuelling amount	30.6	litter	Fire and Disaster Management Agency website
Refuelling speed	32.5	litter/minute	Fire Service Act
Fuel efficiency	21.9	km/liter	MLITT (2017)

yen, respectively. Therefore, the total net benefit is negative, −805.9 billion yen (−US\$73.3 billion), implying that the Japanese government should not promote the diffusion and usage of EVs. This conclusion mainly comes from the fact that the opportunity cost of waiting for EVs to recharge is remarkably large.

The upper bound value of the opportunity cost is calculated in the simulation as mentioned before because all EV owners are assumed not to recharge their EVs at home but at outdoor fast chargers 22.5 times per year. Therefore, we reduce the number of recharges at outdoor fast chargers (i.e., increase the number of recharges at home) and recalculate the cost and benefit. When owners recharge their EVs at home, the opportunity cost of waiting for EVs to recharge is assumed to be zero. For example, this could be because the recharge is performed overnight.

Fig. 3 Cost and benefit of EVs by number of outdoor recharges

The recalculated costs and benefits are depicted in Fig. 3. The x- and y-axes represent the number of recharges and monetary value of the cost or benefit, respectively. In the basic simulation, the number of outdoor recharges is set to 22.5. As shown in Fig. 3, we observe that the cost (i.e., sum of the construction cost and opportunity cost of recharge wait time) decreases as the number of outdoor recharges decreases. When the number of recharges decreases to 12, the benefit is greater than the cost, implying that the promotion of EVs improves social welfare. Twelve is approximately half of 22.5, so if less than one of every two recharges is done outdoors, the spread of EVs will be an efficient countermeasure against climate change. Since charging EVs takes longer than refuelling gasoline or diesel vehicles, it is necessary to examine in particular how many times EV owners will use outdoor fast chargers. In addition, to improve social welfare further, it is important for policymakers and manufacturers to develop high-performance fast chargers.

4 Concluding Remarks

Since automobiles greatly contribute to GHG emissions in Japan (i.e., 15.4% of the total), it is important to examine how to efficiently reduce emissions from automobile. A carbon tax on fuel consumption was implemented in Japan in 2012 to reduce GHG emissions from vehicles. However, the tax rate, 289 yen (US\$2.6) per t-CO₂, has been criticized as being too low compared to the rates of other countries and the SCC determined by Wang et al. (2019). However, multiple taxes are already imposed on vehicles in Japan. Considering taxes such as the *vehicle acquisition tax* and VAT, the entire tax rate on carbon, that is, the ECR, may not be small. Focusing on automobiles in Japan, this chapter first gave an overview of the complicated vehicle tax system and examined the entire ECR on vehicles.

Different from the OECD (2016) and OECD (2018), when calculating the ECR on vehicles in Japan, we consider the entire vehicle tax system, including taxes on vehicle purchase and possession, from the perspective of life cycle assessment. The final ECR on vehicles in Japan is estimated to be 128.9 thousand yen (US\$1.17 thousand) per t-CO₂, suggesting that the ECR is quite large. This is because the tax rates for vehicle purchase and possession are high compared to the rate for vehicle usage under the vehicle tax system in Japan. Therefore, although the carbon tax rate on fuel consumption is small in Japan, the ECR is rather high. For further improvement of countermeasures against climate change, the Japanese government should shift its attention to vehicle usage from vehicle purchase and possession.

Second, we completed a cost-benefit analysis of EVs, which are projected to become a main type of vehicle in the future (IEA 2019). The benefit of EVs is calculated as the monetary value of GHG emissions reduction when all vehicles are replaced with EVs. The cost is the sum of the construction cost of fast chargers and the opportunity cost of the EV recharge wait time. For the basic calculation, we assume that EV owners do not recharge their EVs at home but at outdoor fast chargers. In that case, the cost and benefit are estimated to be 1722 and 916 billion

yen (US\$15.7 and 8.3 billion), respectively. That is, the diffusion of EVs is not an efficient measure for reducing GHG emissions. However, if owners recharge their EVs at home once of every two charges, the net benefit becomes positive, suggesting that the opportunity cost of waiting for recharges is a key factor in whether EVs can play a role in mitigating climate change. Therefore, it is important for policymakers to examine how often EV owners use outdoor fast chargers as well as to develop higher performance fast chargers. Additionally, to make effective use of the waiting time for recharging, it is desirable to construct fast chargers. This chapter introduces strong assumptions for estimating the ECR and the cost-benefit analysis. Future research needs to relax the assumptions to examine them precisely.

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