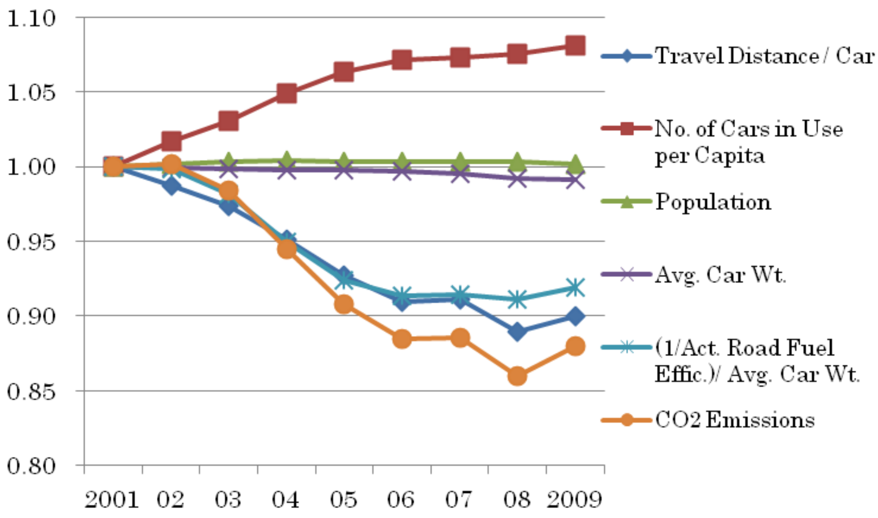


Figure 2. Trends in change factors related to CO_2 emissions from passenger cars in Japan [avg. = average; wt. = weight; act. = actual; effic. = efficiency]

Table 2. Annual average change rates of change factors in four study cases

Study Case	Travel Distance / Car	No. of Cars in Use per Capita	Avg. Car Wt.	(1/Act. Road Fuel Effic.)/Avg. Car Wt.	Population
Trend 2001–2009	−0.01384	0.00938	−0.00116	−0.01099	0.00019
Trend 2001–2005	−0.02033	0.01472	−0.00056	−0.02061	0.00089
Trend 2005–2009	−0.00735	0.00404	−0.00176	−0.00138	−0.00051
Optimistic Trend	−0.02033	0.00404	−0.00176	−0.02061	−0.00051

3.2 Annual Average Change Rates of Change Factors

Table 2 shows annual average change rates of the five change factors for the four study cases. The annual average change rates were calculated by Eq. 9 and 10, and each annual average change rate in the optimistic trend case took a maximum decreasing or minimum increasing rate of each change factor among the other three study cases. The absolute values of the annual average change rates of the change factors over the period 2001 to 2005 were higher than those over the periods 2001 to 2009 and 2005 to 2009, except for the average passenger car weight in use.

3.3 Results of Projections

Table 3 shows projected CO_2 emissions from Japanese passenger cars in 2020 and Figure 3 shows the trends for the four study cases up to 2020. Figure 4 (a), (b), (c), and (d) show changes in CO_2 emissions from each change factor from the 2009 level for each study case.

The projections based on the trends in the change factors over the period 2001 to 2009 showed that aggregate CO_2 emissions in 2020 will decrease to a level of 99.0 million metric tons-CO_2, which corresponds to 81.3% of the 2009 level but 117% of the 1990 level and accounts for a decrease of 22.7 million metric tons-CO_2 from the 2009 level (Table 3 and Figure 3). Decreases in the travel distance per passenger car in use and improvement in actual road fuel efficiency per average weight of passenger cars in use will primarily induce the reduction in aggregate CO_2 emissions: decreases in CO_2 emissions from the above two factors will be 17.5 and 13.5 million metric tons-CO_2 in 2020, respectively (Figure 4 (a)). While a rise in the per-capita number of passenger cars will contribute to an increase in CO_2 emissions, the two decreasing factors will overcome this increase. On the other hand, influences of changes in the average car weight and population will be small.

The projections based on the trend in the change factors over the period 2001 to 2005 showed that aggregate CO_2 emissions in 2020 will decrease to a level of 85.2 million metric tons-CO_2, which corresponds to 70% of the 2009 level and almost equals the 1990 level, and account for a decrease of 36.6 million metric tons-CO_2 from the 2009 level (Table 3 and Figure 3). The same change factors as for the projections based on the trends over the period 2001 to 2009 will induce the reduction in aggregate CO_2 emissions: decreases in CO_2 emissions induced by the decrease in the travel distance per passenger car and improvement in the actual road fuel efficiency per average weight of passenger cars will be 24.1 and 24.5 million metric tons-CO_2 in 2020, respectively (Figure 4 (b)). Influences of changes in the average car weight and population will be as small as the projections based on those trends over the period 2001 to 2009.

On the other hand, the projections based on the trends in the change factors over the period 2005 to 2009 showed that aggregate CO_2 emissions in 2020 will decrease to a level of 112.3 million metric tons-CO_2, which corresponds to 92.2% of the 2009 level but 132% of the 1990 level and accounts for a decrease of 9.5 million metric tons-CO_2 from the 2009 level (Table 3 and Figure 3). The decrease in the travel distance per passenger car will primarily induce the reduction in aggregate CO_2 emissions: the reduction in CO_2 emissions caused by the decrease will be 9.78 million metric tons-CO_2 in 2020 (Figure 4 (c)). Influences of changes in the average car weight, population, and actual road fuel efficiency per average weight of passenger cars are small for this study case.

Under the optimistic case, aggregate CO_2 emissions in 2020 will decrease to a level of 74.5 million metric tons-CO_2, which corresponds to 61.2% of the 2009 level and 87.8% of the 1990 levels and accounts for decrease of 47.3 million metric tons-CO_2 from the 2009 level (Table 3 and Figure 3). The same change factors as the projections based on the trends over the periods 2001 to 2009 and 2001 to 2005 will induce the reduction in aggregate CO_2 emissions, but the influence of a rise in the per-capita number of cars will be relatively small (Figure 4 (d)). The optimistic case is expected to largely decrease CO_2 emissions. However, this case seems to be unrealistic because both large decreases in the travel distance per passenger car and improvement in actual road fuel efficiency, without increase in the per-capita number of passenger cars, may not simultaneously continue.

The projections showed that CO_2 emissions from Japanese passenger cars will continue to decrease, with the decrease in the travel distance per passenger car in use and improvement of actual road fuel efficiency per average weight of passenger cars in use primarily inducing the reduction.

The projections using the PMLI method provide a baseline of the forecast CO_2 emissions from car travel; and could be utilized in the construction of forecasting and backcasting scenarios which help to make valid climate policies for reducing CO_2 emissions from the car travel. The PMLI method is a macroscopic analytical tool, and the results of the projections are trace of the future path based on the historical trends: results of the projections are approximate. The PMLI method thus could be used by combining with other forecasts, such as increases in the number of hybrid and electric passenger cars induced by the future measures and technological improvements, for constructing the scenarios.

Table 3. Projected aggregate CO_2 emissions in 2020 for four study cases (million metric tons-CO_2)

Study Case	Projected CO_2 Emissions in 2020	Changes in CO_2 Emissions in 2020 from 2009 Level	Comparison of CO_2 Emissions (CO_2 Emissions in 1990: 84.8)	
			2020/1990	2020/2009
Trend 2001–2009	99.0	−22.7	1.168	0.813
Trend 2001–2005	85.2	−36.6	1.005	0.700
Trend 2005–2009	112.3	−9.5	1.324	0.922
Optimistic Trend	74.5	−47.3	0.878	0.612

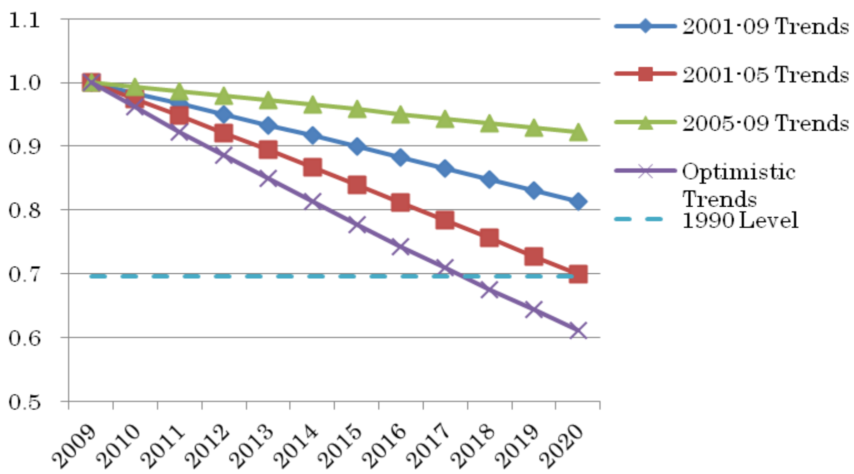
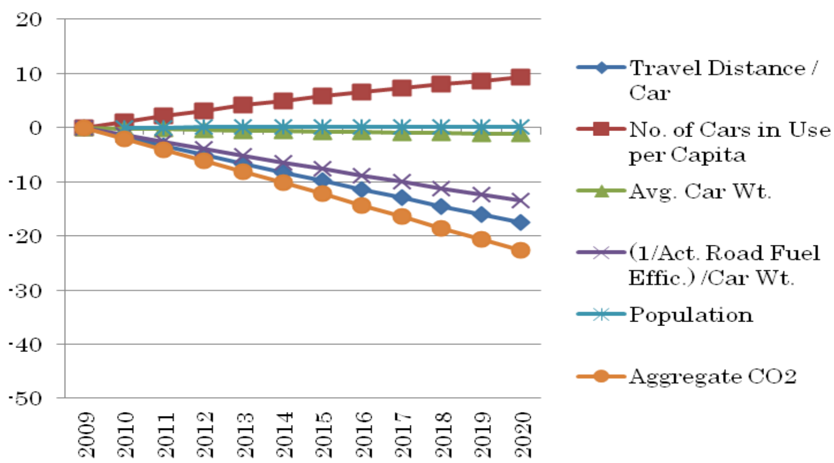
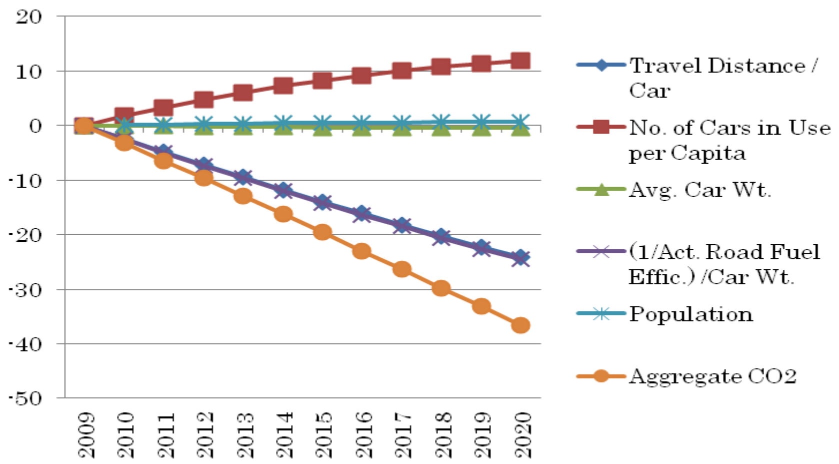


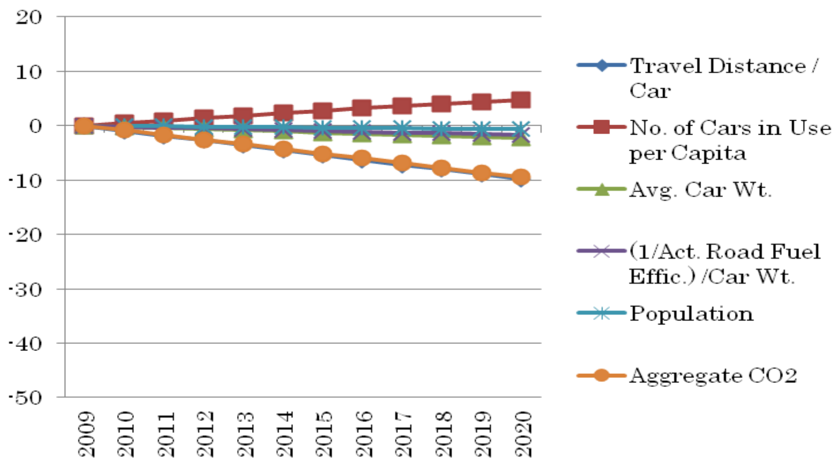
Figure 3. Trends in projected CO_2 emissions for the four study cases (2009 = 1.0)



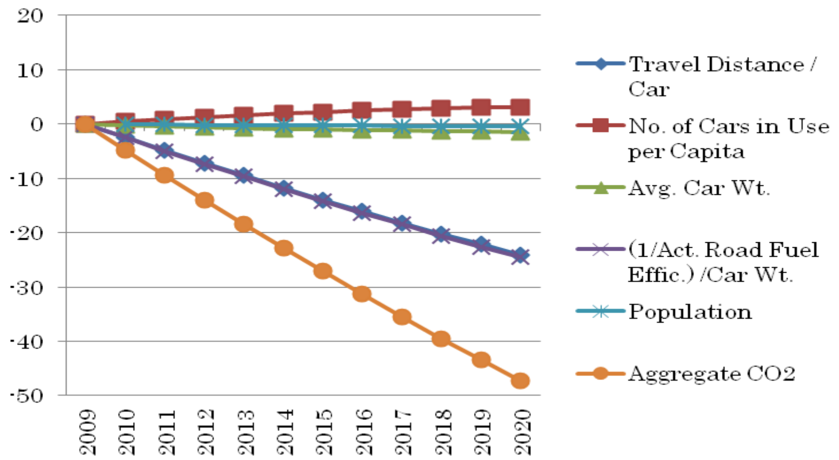
(a)



(b)



(c)



(d)

Figure 4. Trends in CO_2 emissions due to change factors from the 2009 level (million metric tons-CO_2): (a) 2001–2009 trends, (b) 2001–2005 trends, (c) 2005–2009 trends, and (d) optimistic trends

Table 4. Projection results using the PMLI method and the method using the techniques of RLI method: changes in CO_2 Emissions due to change factors from the 2009 level based on the trends over the period 2001 to 2009 (million metric tons-CO_2)

Year	Base Method	Travel Distance per Car	No. of Cars in Use per Capita	Avg. Car Wt.	(1/Act. Road Fuel Effic.)/Avg. Car Wt.	Population	Total
2015	MLI	−9.81	5.84	−0.73	−7.65	0.12	−12.25
	RLI	−10.02	6.34	−0.81	−7.89	0.13	−12.24
	RLI/MLI	1.02	1.09	1.10	1.03	1.12	1.00
2020	MLI	−17.54	9.26	−1.18	−13.46	0.19	−22.72
	RLI	−18.20	10.87	−1.42	−14.21	0.23	−22.72
	RLI/MLI	1.04	1.17	1.21	1.06	1.23	1.00

3.4 Comparison of Projection Results Using Techniques of the MLI Method (PMLI Method) and RLI Method

The projection results using the PMLI method was compared with those using the techniques of the RLI method (Table 4).

The RLI method equally distributes the interaction term to all simultaneously changed factors in the same interaction term (Sun, 1998). In the method using the techniques of the RLI method, changes in each factor over a future period from the base year "*y*" to a year "*t*" are given by Eq. 18 and 19, instead of Eq. 13 and 14 given for the MLI method.

$$\Delta CO_{2F} = \alpha TCO_2^y (1 + \frac{1}{2}\beta T) \quad (18)$$

$$\Delta CO_{2D} = \beta TCO_2^y (1 + \frac{1}{2}\alpha T) \quad (19)$$

Table 4 shows the changes in CO_2 emissions due to change factors from the 2009 level based on the trends over the period 2001 to 2009 projected using the PMLI method and the method using the techniques of RLI method. Aggregate reduction of CO_2 emissions was the same between the results using the two methods. However, changes in CO_2 emissions from each factor given by the projection using the PMLI method were smaller than those given by the method using the techniques of RLI method in absolute value with maximum 20%, because of the differences between the analysis methods: the MLI method attributes the interaction term to the increasing factors only when both increases and decreases in the simultaneously changed factors exist in the same interaction term.

4. CONCLUSIONS

This study presented a method (PMLI method) of projecting CO_2 emissions from car travel using techniques of the MLI decomposition method. CO_2 emissions from Japanese passenger cars up to 2020 were then projected.

The PMLI method quantitatively identifies the underlying driving forces responsible for the future changes in CO_2 emissions from car travel, and provides a baseline for future CO_2 emissions. The PMLI method could be utilized in the construction of scenarios for reducing CO_2 emissions from car travel. Moreover, this method could be applicable for other Asian regions, countries, and cities besides Japan where relevant data are available.

The projections of CO_2 emissions from Japanese passenger cars up to 2020 showed that CO_2 emissions in 2020 will decrease to the 1990 level on the basis of the trends in change factors observed over the period 2001 to 2005. Decreases in the travel distance per passenger car in use and improvements in actual road fuel efficiency per average weight of passenger cars in use will primarily induce these emissions reductions. This empirical analysis did not consider influences of changes in the engine efficiency per class of cars, car age in the fleet composition, road conditions, and driving manners, but the actual road fuel efficiency per car weight was used as a proxy including those factors. Further studies of identifying influences of changes in each factor above are needed for more precise analysis.

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