

Carbon Dioxide Emissions from Japanese Passenger Cars up to 2020: Projection Using Modified Lapeyres Decomposition Techniques

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Abstract: Index decomposition methods have been widely used for quantitative identification of historical trends in factors related to changes in objective variables when examining environmental and energy issues; however, index decomposition methods have been rarely used for projecting carbon dioxide (CO₂) emissions. A method, called Modified Laspeyres Index method for Projection (PMLI method), was developed for projecting CO₂ emissions from car travel using index decomposition techniques. CO₂ emissions from Japanese passenger cars up to 2020 were then projected by using this method. The CO₂ emissions in 2020 will decrease to the 1990 level on the basis of the trends in factors observed over the period 2001 to 2005. Decreases in travel distance per passenger car in use and improvement of actual road fuel efficiency per average car weight will primarily induce these decreases. The PMLI method could be utilized in the construction of scenarios for reducing CO₂ emissions from car travel.

Keywords: Index Decomposition Analysis, CO₂ Emissions, Passenger Cars

1. INTRODUCTION

CO₂ emissions from Japanese transport sector accounted for 20.1% of the aggregate CO₂ emissions in 2009 (GIO, 2011). While CO₂ emissions from passenger cars peaked in 2001 and then began to decline, they were as much as 36.1% above the 1990 level in 2009 (GIO, 2011). Reducing CO₂ emissions from passenger cars is a key factor in meeting the reduction target in Japan.

Transportation problems are often sustainability problems, and are complex, long reaching, and difficult to address with incremental policies (Barrella and Amekudzi, 2011). Moreover, planning for issues such as reduction in CO₂ emissions from passenger cars involves a high degree of uncertainty, and requires analysis of future transportation conditions. Projecting and scenario construction are two of the applicable approaches for this planning. The projections estimate the potential changes for the cases where factors follow the historical trends and would provide a basis for constructing scenarios. On the other hand, the scenarios are formulated to describe alternative future developments of complex systems that are either inherently unpredictable, are insufficiently understood, or have high scientific uncertainties (Nakicenovic, 2000), and the scenarios help to make robust strategic choices (Zegras *et al.*, 2004).

Many previous studies have discussed projecting and scenario construction. Myers and Kitsuse (2000) argued that a projection is not a prediction but merely the result of entering hypothetical assumptions into a mechanistic quantitative procedure, and projections are only mechanical exercises that spell out the future implications of current or past trends without

assessing the validity of the assumptions that are used to make the projections. Kwon (2005) pointed out that a precise forecast of the trends in CO₂ emissions would be impossible because of the huge uncertainty of changes in future travel behavior and technology. Linderoth (2002) showed that forecasting errors in the annual publication of Energy Policies by the International Energy Agency (IEA) were caused by inaccurate growth rate expectations, especially in industry, and an unexpectedly high growth rate in energy demand in the transport sector can be a severe problem in the future regarding commitments to reduce greenhouse gas emissions. Agnolucci *et al.* (2009) agreed that the past is not necessarily a good guide for the future, but insisted that, at least as far as carbon emissions are concerned, assessing historical trends is useful to get an idea of the drivers influencing a particular ratio of the strength of instruments needed to shape its future evolution.

According to Geurs and Wee (2004), two kinds of scenarios can be distinguished: projective and prospective scenarios. A projective scenario is called “forecasting”, and its starting point is the current situation; extrapolation of current trends results in future images. A prospective scenario is called “backcasting” and its starting-point is a possible or a desirable future situation, usually described by a set of goals or targets established by events assumed to occur between the current and future situations (Geurs and Wee, 2004). Forecasting studies are common in transport research to assess problems due to current and future transport activity based on the continuation of current socio-economic trends, but the backcasting studies are less commonly applied in transport analyses (Geurs and Wee, 2004). Borjeson *et al.* (2006) argued that if researchers and planners want to investigate what will happen during some specified near future events of great importance for future development, forecasts and what-if type scenarios are of interest, but if they want to search for scenarios fulfilling specific targets, normative scenarios such as backcasting should be the choice. Barrella and Amekudzi (2011) pointed out that backcasting is deemed appropriate when the planning time horizon is long, because forecasting would lead to considerable uncertainty in the impact and risks.

Quantitative identification of the driving forces that impact past and future changes is one of the key steps for forecasting and backcasting. Index decomposition methods are useful for quantitatively identifying the past driving forces and for assessing the current conditions of an objective variable based on historical trends. According to Agnolucci *et al.* (2009), index decomposition analysis is a useful technique both to generate quantitative scenarios and to cast light on the socio-economic conditions that they imply. Steenhof *et al.* (2006) argued that an index decomposition analysis provides a basis for the manipulation of key drivers operating within the sector and an assessment of these changes through the means of scenario analysis. Moreover, Steenhof (2007) confirmed that index decomposition is an easy to use, transparent, and highly accessible approach for construction of a baseline that represents the forecast of emissions using a business as usual (BAU) scenario. Ang and Zhang (2000) pointed out that while the majority of past studies using index decomposition methods were concerned with historical analysis, the index decompositions are useful in “what if” types of projections where future energy demand or gas emissions are projected for the cases where major factors are assumed to remain unchanged or to follow the identified historical trends.

A large number of empirical studies on projecting and scenario construction that included CO₂ emissions from car travel have been conducted. Steenhof *et al.* (2006) investigated the greenhouse gas emission profile of Canada’s surface freight transportation sector over the period 1990 to 2012, in which they used the index decomposition technique to analyze historical trends up to 2003, and created the projective scenarios for 2012 by illustrating potential changes into the future. Steenhof (2007) conducted an index decomposition of CO₂ emissions from China’s electricity sector over the period 1980 to 2002

using the refined Laspeyres index (RLI) decomposition method, and then created scenarios to 2020 based upon a thorough literature review and on projections for the development of China's economy and energy sector available from various entities within China's central government. Hatzigeorgiou *et al.* (2010) decomposed changes in energy-related CO₂ emissions in Greece and in the 25 European Union (EU) countries over the period 1995 to 2020 by using the logarithmic mean Divisia index (LMDI) decomposition method with historical data from 1990 to 2000 and estimates of a baseline scenario from 2000 to 2020 stemming from the developed energy simulation model. Kwon (2005) projected CO₂ emissions from car travel in Great Britain over the period 2000 to 2030 by building various scenarios based on an index decomposition of the historical trends. Moreover, Agnolucci *et al.* (2009) compared two different scenarios of UK energy use up to 2050 by assuming future trends based on historical index decomposition ratios over the period 1970 to 2002 using the so-called Kaya identity.

Previous studies, as shown above, have widely used index decomposition methods for assessing historical trends in CO₂ emissions, including those from car travel; however, they have rarely used the index decomposition techniques for projecting CO₂ emissions from change factors. While Sun (2001) proposed a method using techniques of the RLI method of projecting energy demand in the EU-15 countries over the period 1998 to 2010, Mishina *et al.* (2011) and Mishina and Muromachi (2012) pointed out theoretical problems with the RLI method of attributing and distributing interaction terms to the related factors. Mishina *et al.* (2011) then proposed the modified Laspeyres index (MLI) method that provides more reliable and accurate results and more reasonable ways of attributing and distributing the interaction terms than existing index decomposition methods. If techniques of the MLI method are available for projecting CO₂ emissions from change factors related to car travel, the future path of CO₂ emissions could be traced by quantitatively identifying the driving forces, and would be helpful to construct precise forecasting and backcasting scenarios for reducing CO₂ emissions from car travel.

This study has two objectives. First, a method was developed for projecting CO₂ emissions from change factors related to car travel by using techniques of the MLI method. Second, CO₂ emissions from Japanese passenger cars up to 2020 were projected by using the developed method for four study cases based on past trends in the change factors related to car travel over the period 2001 to 2009. The year 2009 was chosen as the base year.

2. METHODOLOGY

A method, called modified Laspeyres index method for projection (PMLI method), of projecting CO₂ emissions from change factors related to car travel was developed. The PMLI method uses techniques of the MLI method. The PMLI method quantitatively identifies the underlying driving forces responsible for the future changes in CO₂ emissions from car travel.

2.1 The Modified Laspeyres Index (MLI) Method

The MLI method was proposed by Mishina *et al.* (2011). This method attributes the interaction term to simultaneously changed factors when all simultaneously changed factors increase or decrease in the same interaction term, but it 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. Moreover, this method distributes the interaction term to the related factors in proportion to the symmetric rates of change in each factor.

Mishina and Muromachi (2012) showed that the MLI method would generate a more valid decomposition of the changes in CO₂ emissions from car travel by reasonably accounting for the attribution and distribution of the interaction terms to the related factors than the RLI and LMDI methods.

In a two-change-factor model (F, D) comprising the change in CO₂ emissions (ΔCO_2), the change in each factor from a base year “0” to a year “ t ” is given by

$$\Delta CO_{2F} = \Delta F D^0 + \frac{a}{a+b} \Delta F \Delta D \tag{1}$$

$$\Delta CO_{2D} = F^0 \Delta D + \frac{b}{a+b} \Delta F \Delta D \tag{2}$$

$$a = \frac{\Delta F}{(F^0 + F^t)/2}, b = \frac{\Delta D}{(D^0 + D^t)/2} \tag{3}$$

where a and b represent the symmetric rates of change in each factor, F and D . When $\Delta F > 0$ and $\Delta D < 0$, $b = 0$; when $\Delta F < 0$ and $\Delta D > 0$, $a = 0$; and when $\Delta F < 0$ and $\Delta D < 0$, replace $a/(a+b)$ and $b/(a+b)$ with $1 - [a/(a+b)]$ and $1 - [b/(a+b)]$, respectively.

In a four-change-factor model (x_1, x_2, x_3, x_4), the change in factor x_1 is given by

$$\Delta CO_{2x_1} = \Delta x_1 \left(x_2^0 x_3^0 x_4^0 + \frac{a_1}{a_1+a_2} \Delta x_2 x_3^0 x_4^0 + \frac{a_1}{a_1+a_3} x_2^0 \Delta x_3 x_4^0 + \frac{a_1}{a_1+a_4} x_2^0 x_3^0 \Delta x_4 \right. \tag{4}$$

$$\left. + \frac{a_1}{a_1+a_2+a_3} \Delta x_2 \Delta x_3 x_4^0 + \frac{a_1}{a_1+a_2+a_4} \Delta x_2 x_3^0 \Delta x_4 + \frac{a_1}{a_1+a_3+a_4} x_2^0 \Delta x_3 \Delta x_4 + \frac{a_1}{a_1+a_2+a_3+a_4} \Delta x_2 \Delta x_3 \Delta x_4 \right)$$

where $a_i = \frac{\Delta x_i}{(x_i^0 + x_i^t)/2}$ $i = (1, 2, 3, 4)$

2.2 The PMLI Method

The PMLI method assumes that change factors related to car travel follow identified historical trends over a future period.

According to the MLI method, the change in each factor from a base year “ y ” to a future year “ t ” in a two-change-factor model (F, D) (Figure 1), comprising the change in CO₂ emissions (ΔCO_2), is given by

$$CO_2^y = F^y \times D^y \tag{5}$$

$$CO_2^t = F^t \times D^t = CO_2^y + \Delta CO_2 = CO_2^y + (\Delta CO_{2F} + \Delta CO_{2D}) \tag{6}$$

$$\Delta CO_{2F} = \Delta F D^y + \frac{a}{a+b} \Delta F \Delta D \tag{7}$$

$$\Delta CO_{2D} = F^y \Delta D + \frac{b}{a+b} \Delta F \Delta D \tag{8}$$

where a and b represent the symmetric rate of change in each factor, F and D , same as Eq. 3.

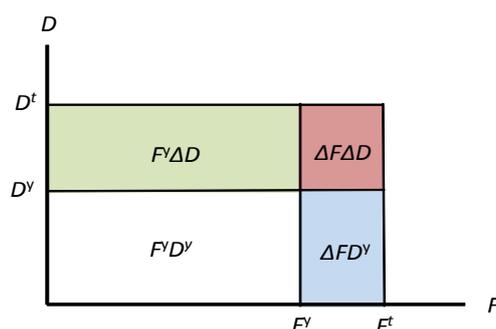


Figure 1. Concept underlying changes in factors in a two-change-factor model

Then, we defined α and β as annual average change rates for change factors over a past period on the basis of base year “y”; hence, α and β are given by

$$\alpha = (\text{Annual average change in factor } F \text{ over a past period}) / F^y \quad (9)$$

$$\beta = (\text{Annual average change in factor } D \text{ over a past period}) / D^y \quad (10)$$

where F^y and D^y represent the magnitude of each factor, F and D , in the base year “y”.

Changes in each factor over a future period from the base year “y” to a year “t” are then given by

$$\Delta F = \alpha T F^y \quad (11)$$

$$\Delta D = \beta T D^y \quad (12)$$

where $T = t - y$

Eq. 7 and 8 are then expressed by

$$\Delta CO_{2F} = \alpha T CO_2^y (1 + \frac{a}{a+b} \beta T) \quad (13)$$

$$\Delta CO_{2D} = \beta T CO_2^y (1 + \frac{b}{a+b} \alpha T) \quad (14)$$

$$a = \frac{\Delta F}{(F^y + F^t)/2} = \frac{\alpha T}{1 + \alpha T/2}, b = \frac{\Delta D}{(D^y + D^t)/2} = \frac{\beta T}{1 + \beta T/2} \quad (15)$$

where a and b represent the symmetric rate of change in each factor, F and D . When $\Delta F > 0$ and $\Delta D < 0$, $b = 0$; when $\Delta F < 0$ and $\Delta D > 0$, $a = 0$; and when $\Delta F < 0$ and $\Delta D < 0$, replace $a/(a+b)$ and $b/(a+b)$ with $1 - [a/(a+b)]$ and $1 - [b/(a+b)]$, respectively.

In the four-change-factor model (x_1, x_2, x_3, x_4) , the future change in factor x_1 is given by

$$\begin{aligned} \Delta CO_{2x_1} = & \left(\alpha_1 T CO_2^y \right) \left[1 + \left(\frac{a_1}{a_1 + a_2} \alpha_2 + \frac{a_1}{a_1 + a_3} \alpha_3 + \frac{a_1}{a_1 + a_4} \alpha_4 \right) T \right. \\ & + \left(\frac{a_1}{a_1 + a_2 + a_3} \alpha_2 \alpha_3 + \frac{a_1}{a_1 + a_2 + a_4} \alpha_2 \alpha_4 + \frac{a_1}{a_1 + a_3 + a_4} \alpha_3 \alpha_4 \right) T^2 \\ & \left. + \left(\frac{a_1}{a_1 + a_2 + a_3 + a_4} \alpha_2 \alpha_3 \alpha_4 \right) T^3 \right] \end{aligned} \quad (16)$$

where $a_i = \frac{\alpha_i T}{1 + \alpha_i T / 2} \quad i = (1, 2, 3, 4)$

3. PROJECTING CO₂ EMISSIONS FROM JAPANESE PASSENGER CARS UP TO 2020

3.1 Scope of Study and Data

CO₂ emissions from Japanese passenger cars up to 2020 were projected using the PMLI method for four study cases: based on the trend in change factors over the period 2001 to 2009, when CO₂ emissions from Japanese passenger cars peaked in 2001 and then began to decline; the trend over the period 2001 to 2005, when CO₂ emissions reduced at a high rate; the trend over the period 2005 to 2009, when the CO₂ emissions reduced at a low rate; and an optimistic trend, taking a maximum decreasing or minimum increasing rate for each change factor among the other three study cases. The year 2009 was chosen as the base year because it provided the latest statistical data available.

Five change factors were considered: travel distance per passenger car in use (*D*: km/car); per-capita number of passenger cars in use (*N*); population (*P*); average weight of passenger cars in use (*W*: metric tons/car); and reciprocal of actual road fuel efficiency per average weight of passenger cars in use (*F*: (1/km/L)/(metric tons/car)). While car weight/size, car age in the fleet composition, actual engine efficiency per class of cars, road conditions such as congestion, and driving manners probably influence the actual fuel consumption for calculating the actual road fuel efficiency, we presumed that the fuel efficiency depended solely on car weight. Moreover, the CO₂ emission factors (*C*) 2.32 and 2.59 metric tons-CO₂ per 1,000 liters are used as calculated for gasoline and diesel, respectively, on the basis of the data published in GIO (2011). The CO₂ emissions (*CO₂*: metric tons) are then given by

$$CO_2 = D \times N \times P \times W \times F \times C \quad (17)$$

The historical data used for calculating the average annual change rate were derived from statistical data drawn from the public domain in Japan (Table 1). The average weight of standard and small cars is estimated by combining the number of cars in use in each car-weight category and the central weight value for each weight category. Because statistical data on the average weight of mini-cars (cars with less than 660 cm³ in engine displacement) are not available, an average weight of 850 kg per mini-car is estimated by referring to the catalog data for mini-cars manufactured by major automakers. More details can be found in Mishina *et al.* (2011).

Figure 2 shows the historical trends in the changes in CO₂ emissions and the five

change factors over the period 2001 to 2009. CO₂ emissions from passenger cars declined continuously at a high rate over the period 2001 to 2005 and at a low rate over the period 2005 to 2009. Travel distance per passenger car and reciprocal of actual road fuel efficiency per average weight of passenger cars tended to decrease but have turned to a low decreasing rate since 2005. On the other hand, per-capita number of passenger cars increased continuously but has turned to a low increasing rate since 2005. Average car weight and population were relatively constant but have tended to decrease slightly since 2005.

Mishina *et al.* (2011) quantitatively identified the two dominant factors in the decline in CO₂ emissions over the period 2001 to 2008 using the MLI method: the decrease in the travel distance per passenger car in use and improvement in the actual road fuel efficiency per average weight of passenger cars in use. A 45% rise in the gasoline price from 2001 to 2008 would help to induce the decrease in the travel distance per passenger car and improvement in the actual road fuel efficiency per average weight of passenger cars. Moreover, the Japanese government's "green tax" scheme from 2001 that provides tax incentives to purchasers of fuel-efficient and low-emission cars may have promoted the increase in the number of higher fuel efficiency cars and mini-cars to some extent. The decrease in the average car weight was primarily caused by the increase in the number of mini-cars in place of standard and small cars. On the other hand, changes in per-capita income would not affect the changes in the related factors, because the per-capita income was relatively constant over the period 2001 to 2009.

Table 1. Statistical data for passenger cars in Japan [avg. = average; wt. = weight; J.yen = Japanese yen (93.52 J.yen/US Dollar, 130.14 J.yen/Euro in 2009, yearly-average)]

Year	Travel Distance (10 ⁶ km) ¹⁾			Number of Cars in Use (10 ³) ²⁾			Fuel Consumption (10 ³ kL) ¹⁾			Avg. Car Wt. ²⁾ (metric tons/car)	Population ³⁾ (10 ⁶)	Gasoline Price ⁴⁾ (J.yen/L)	Income ⁵⁾ (10 ⁸ J.yen)
	Except Mini	Mini Car	Total	Except Mini	Mini Car	Total	Gasoline	Diesel	Total				
2001	432,753	77,577	510,331	42,269	10,960	53,229	52,697	6,203	58,900	1.21	127.32	101	399,486
2002	428,960	84,074	513,033	42,392	11,816	54,208	53,429	5,630	59,059	1.21	127.49	100	393,069
2003	422,630	90,986	513,617	42,357	12,664	55,021	53,253	4,867	58,120	1.21	127.69	101	394,867
2004	413,855	97,058	510,914	42,505	13,512	56,017	51,759	4,095	55,854	1.21	127.79	115	401,902
2005	402,274	102,601	504,875	42,474	14,350	56,824	50,340	3,396	53,736	1.21	127.77	128	405,699
2006	390,189	108,721	498,909	41,956	15,281	57,237	49,746	2,690	52,437	1.21	127.77	136	415,412
2007	383,725	116,442	500,166	41,195	16,082	57,277	50,205	2,329	52,534	1.20	127.73	146	419,112
2008	368,235	121,327	489,562	40,528	16,883	57,411	49,162	1,907	51,069	1.20	127.69	146	390,760
2009	368,919	128,585	497,504	40,153	17,484	57,637	50,685	1,608	52,293	1.20	127.51	125	374,129

1) MLIT (2002 to 2010), 2) AIRIA (2002 to 2010), 3) MIC (2010), 4) JEEJ (2010), 5) ESRI (2010)

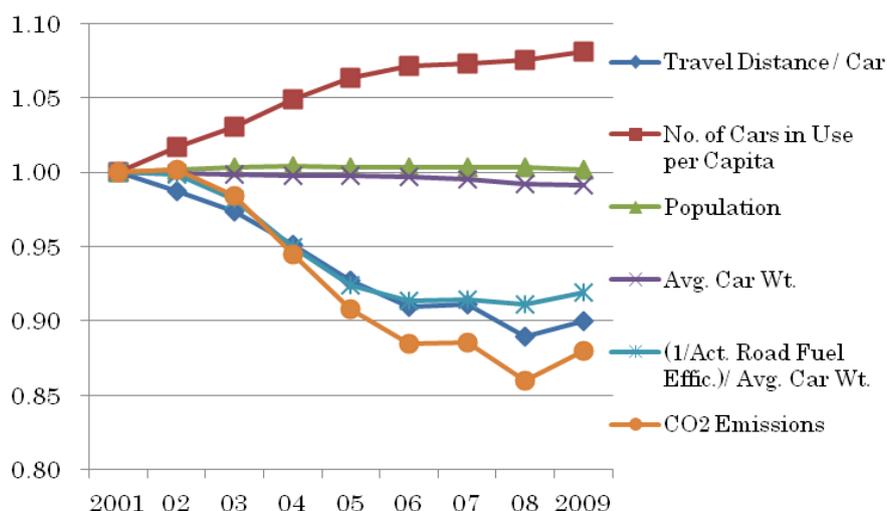


Figure 2. Trends in change factors related to CO₂ emissions from passenger cars in Japan [avg. = average; wt. = weight; act. = actual; effic. = efficiency]

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 CO₂ 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 CO₂ 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 CO₂ emissions in 2020 will decrease to a level of 99.0 million metric tons-CO₂, 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-CO₂ 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 CO₂ emissions: decreases in CO₂ emissions from the above two factors will be 17.5 and 13.5 million metric tons-CO₂ in 2020, respectively (Figure 4 (a)). While a rise in the per-capita number of passenger cars will contribute to an increase in CO₂ 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 CO₂ emissions in 2020 will decrease to a level of 85.2 million metric tons-CO₂, 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-CO₂ 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 CO₂ emissions: decreases in CO₂ 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-CO₂ 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 CO₂ emissions in 2020 will decrease to a level of 112.3 million metric tons-CO₂, 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-CO₂ 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 CO₂ emissions: the reduction in CO₂ emissions caused by the decrease will be 9.78 million metric tons-CO₂ 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 CO₂ emissions in 2020 will decrease to a level of 74.5 million metric tons-CO₂, 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-CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions in 2020 for four study cases (million metric tons-CO₂)

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

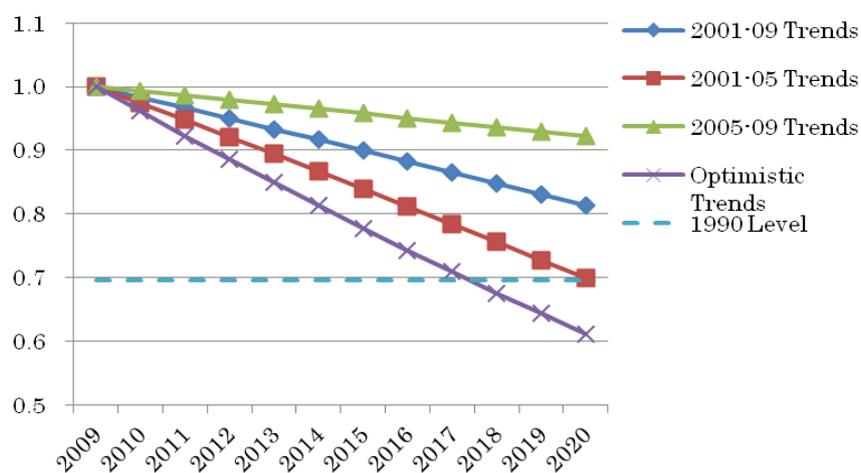
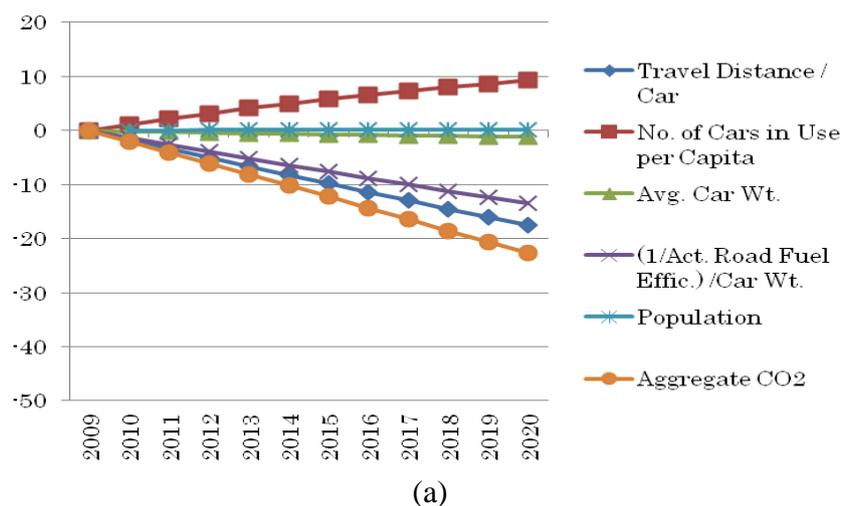


Figure 3. Trends in projected CO₂ emissions for the four study cases (2009 = 1.0)



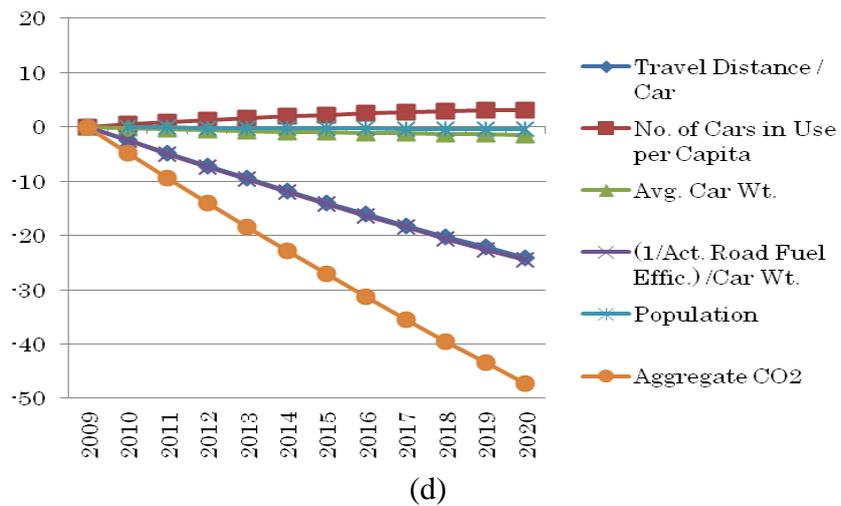
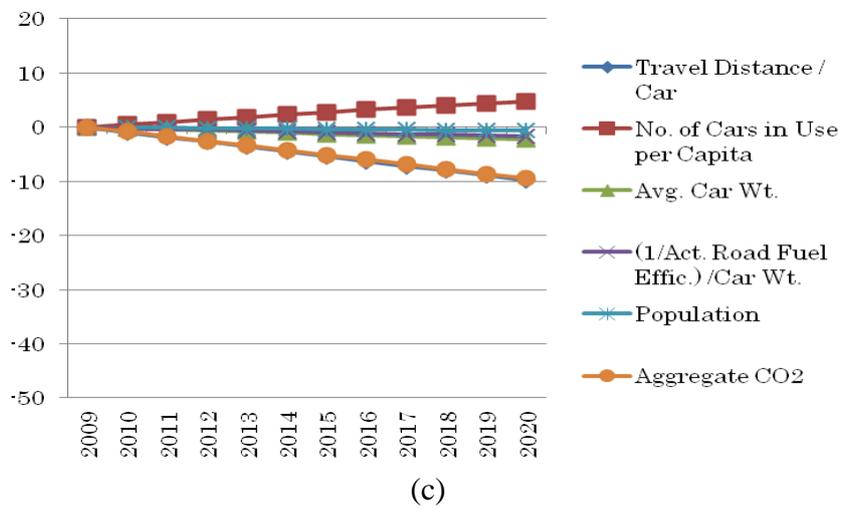
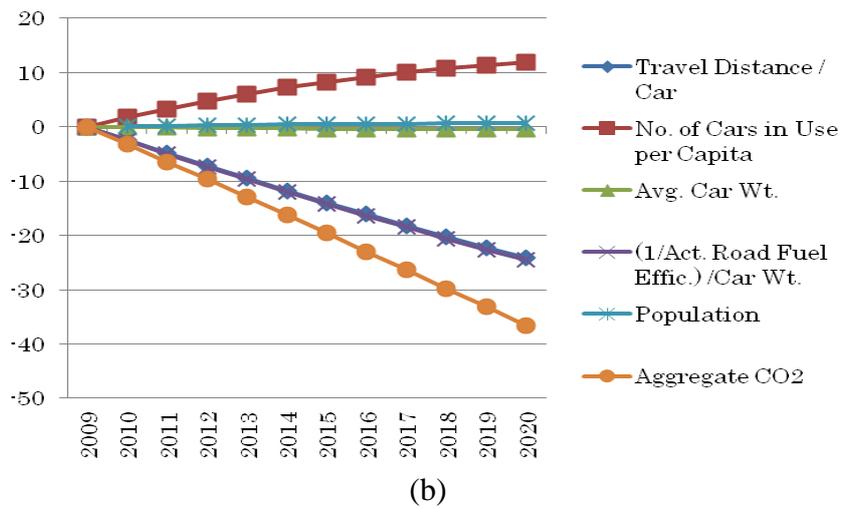


Figure 4. Trends in CO₂ emissions due to change factors from the 2009 level (million metric tons-CO₂): (a) 2001–2009 trends, (b) 2001–2005 trends, (c) 2005–2009 trends, and (d) optimistic trends

Table 4. Projection results using the PMLI method and the method using the techniques of RLI method: changes in CO₂ Emissions due to change factors from the 2009 level based on the trends over the period 2001 to 2009 (million metric tons-CO₂)

Year	Base Method	Travel Distance per Car	No. of Cars in Use per Capita	Avg. Car Wt.	(1/Act. Road Fuel Effc.)/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.

$$\Delta CO_{2F} = \alpha T CO_2^y \left(1 + \frac{1}{2} \beta T\right) \tag{18}$$

$$\Delta CO_{2D} = \beta T CO_2^y \left(1 + \frac{1}{2} \alpha T\right) \tag{19}$$

Table 4 shows the changes in CO₂ 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 CO₂ emissions was the same between the results using the two methods. However, changes in CO₂ 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 CO₂ emissions from car travel using techniques of the MLI decomposition method. CO₂ 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 CO₂ emissions from car travel, and provides a baseline for future CO₂ emissions. The PMLI method could be utilized in the construction of scenarios for reducing CO₂ 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 CO₂ emissions from Japanese passenger cars up to 2020 showed that CO₂ 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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