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Environmental load reduction of substitution of electric vehicles by taking geographical features into account

Yoshinori Kondo[1], Hideki Kato[2], Yoshihiko Karakama[3]
[1]*National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, kondos@nies.go.jp*
[2]*Toyota Transportation Research Institute, 1-1 Wakamiya-cho, Toyota, Aichi 471-0026,kato@ttri.or.jp*
[3]*Association for the Promotion of Electric Vehicles, 6-10-1 Nishi-shinjuku, Shinjuku-ku, Tokyo 160-0023,karakama@apev.jp*

Abstract

Based on assumptions of impacts of road grade on vehicle use and taking vehicle warm up status and auxiliary equipment use into account, the environmental impact of internal combustion engine vehicles (ICEVs) and electric vehicles (EVs) were compared and the effectiveness of deploying EV in areas with elevation gradients was assessed. The JC08 mode was used as the driving cycle for chassis dynamometer tests conducted to investigate the effects on performance of auxiliary equipment use and road grade for ICEV while a driving simulation was used for EV. As a result of substituting ICEV by EV, while CO_2 and CO emissions decreased, NO_x emission increased for several cases. Then, realistic scenarios were set taking vehicle use frequency, auxiliary equipment use, and other factors into account to compare the relationship of residence and workplace areas to changes in CO_2 and air pollutant emissions. Although NO_x emission when the residence area was higher in elevation than the workplace area increased slightly compared to level areas, promotion of EV deployment could be called worthwhile because CO_2 emission reduction was larger than for level areas. However, reduction of NO_x emission related to power generation will be important for reducing all of the environmental burdens associated with EV use.

The results of this research showed that NO_x emission that accompany EV use were higher than for ICEV. In addition, there has been little previous consideration of the effects of auxiliary equipment use, road grade, and other factors on emissions of CO_2 and air pollutants. However, the results of this study have shown that a road grade of only 2-degree grade resulted in a 14% difference in emissions.

Keywords: EV, internal combustion engine vehicle, emissions, passenger car

1 Introduction

Electric vehicles (EVs) produced by major manufacturers have comparable performance to internal combustion engine vehicles (ICEVs). However, due to high cost, adoption by consumers has been slow [1],[2]. The authors used a simulation based on an investigation of long-term use of passenger vehicles and found that if limiting use to once or twice a month was acceptable, there was a high possibility of deployment for EVs currently sold in Japan by major manufacturers even if household recharging was limited to 100 V [3].

On the other hand, based on the Owner Interview OD Survey of the National Road Traffic Census (National Road Traffic Survey) Automobile Origin Destination Survey that is conducted on some weekday and some holiday at a designated time, it was found that many were considering the possibility of switching to EVs [4].

Although there are studies that have considered the possibility of substitution based on vehicle use distance, there are few studies considering the effects of the topographic feature of road grade on EV energy consumption.

In addition to the greenhouse gas carbon dioxide (CO_2), the environmental burden of vehicles includes air pollutant emissions. While the environmental burden of ICEV changes with its warm up state and load, these factors have little effect on EV. Also, the use of auxiliary equipment has a large impact on energy consumption.

This study had the objectives of evaluating the effect of substitution of ICEV by EV on CO_2 and air pollutant emissions while taking into account geographic features, starting condition, and auxiliary equipment use.

2 Research Methods

2.1 ICEV Environmental Burden Evaluation Method

The chassis dynamometer facility at the National Institute for Environmental Studies was used to examine vehicle performance on fuel consumption and emissions. The driving cycle used was the JC08 mode (duration 1204 seconds, total distance 8.2 km) [5] and tests were conducted with no warm up (cold start) and with warm up (hot start). In addition, the tests were carried out using the headlights and air conditioning to assess the effects of auxiliary equipment use on performance.

The effects of road grade were investigated by conducting tests with the road grade set to +2 degrees and –2 degrees during the driving cycle. Table 1 shows the vehicle specifications, and Figure 1 shows the driving cycles used in the test.

Tests combining road grade conditions with auxiliary equipment use were not conducted; the joint effects of these factors were inferred from the test results without road grade condition.

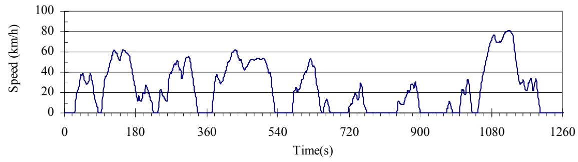

Fig.1 Speed pattern in the JC08 driving cycle

2.2 EV Environmental Burden Evaluation Method

As conducting tests with an EV would have been difficult, a driving simulation was conducted by calculation. The simulation was conducted for three types of EVs with differing battery capacity as shown in Table 1. For these three types of battery capacity, EVs currently sold in Japan were used as references for setting vehicle weight.

Table 1 Vehicle specifications

		Electric Vehicles			ICEV
Items	Unit	V24kWh	V16kWh	V9kWh	
Vehicle weight	kg	1,333	1,219	1,119	990
Battery capacity	kWh	24	16	9	-
Dimension	mm	W1695xH1475			
Frictional resistance : μ		0.011			
Coefficient of air		0.395			

Energy consumption for the running of EVs was derived using reference [3]. The formulas used in the calculation are shown in Equations. (1)–(7).

The energy $P(t)$ [W] consumed to propel a vehicle was calculated from both vehicle specifications and the second-by-second speed data in the JC08 mode driving cycle by using Equations. (1) through (6).

$$P(t) = \eta R(t) V(t) \quad (1)$$

where η is the efficiency at the drive-train, $R(t)$ is the running resistance [N], and $V(t)$ is the vehicle speed [ms^{-1}].

$$R(t) = R_r + R_l(t) + R_a(t) + R_s(t) \quad (2)$$

where R_r is the frictional resistance, R_l is the air resistance, R_a is the acceleration resistance, and R_s is the hill climbing resistance.

$$R_r = \mu M g \quad (3)$$

where μ is the coefficient of friction [$Nm^{-1}s^2kg^{-1}$], M is the vehicle mass [kg], and g is the gravitational constant [9.8 ms^{-2}].

$$R_l(t) = \rho C_d S V(t)^2 / 2 \quad (4)$$

where ρ is the air density [kgm^{-3}], C_d is the coefficient of air resistance, and S is the projection area [m^{-2}].

$$R_a(t) = (M + \delta M)\alpha(t) \quad (5)$$

where δM is the equivalent mass of rotating parts [kg] and $\alpha(t)$ is the acceleration [ms^{-2}].

$$R_s(t) = Mg \sin\theta(t) \quad (6)$$

where $\theta(t)$ is the road inclination [radians].

The running energy consumption E^T required for the use of a car is calculated as

$$E^T = \sum_{t=0, P>0}^{T} P(t) \quad (7)$$

where T is the total time of the JC08 mode driving cycle [s].

The energy consumed per unit distance traveled U^{ET} [$kWhkm^{-1}$] was obtained by dividing E^T by the distance traveled in the JC08 mode driving cycle L[km].

Although there are no direct emissions from EV during use, there are emissions from producing the electricity used for driving. The emission coefficients shown in Table 2 [6][7] were used for the emissions per unit electricity used. Power plant CO emissions were assumed to be zero.

Table 2 Emission factors on producing 1kWh electricity

	Gases		
Unit	CO2	NOx	CO
g/kWh	561	0.2	0

The power train efficiency η in Equation (1) was 0.9 for hot start, 0.7 for cold start, and constant during driving.

The energy consumption for auxiliary equipment use was 300 W for headlight electricity use and constant energy consumption was assumed during testing. The air conditioner was set to have a maximum output of 3 kW, and was assumed to operate at maximum output for the first 360 seconds and 20% of the maximum output during the remaining time of the test cycle. Figure 2 shows the flow chart for deriving vehicle energy consumption and pollutant emissions.

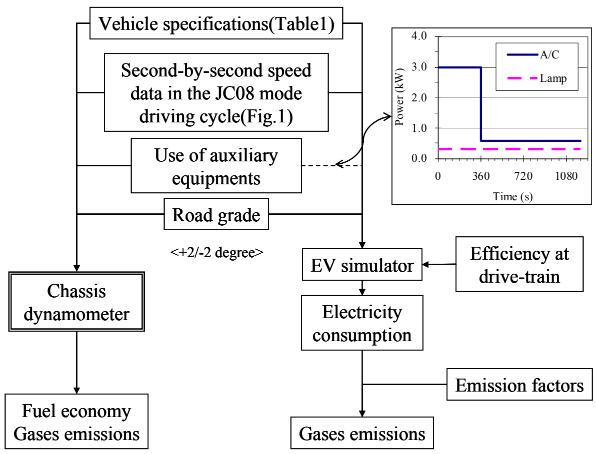

Fig 2. Flowchart for calculating vehicle emissions

2.3 Scenario Setting for Comparing Environmental Burden

The conditions for comparing the environmental burden between ICEV and EV included the assumption of passenger vehicle commuting use, relationship between the residence area and workplace area, vehicle condition, time of day for vehicle use, and use frequency (Table 3). Images of the scenarios are shown in Figure 3. In addition, seasonal auxiliary equipment use was added based on time of day (Table 4).

Table 3 Residence and workplace geographical features and vehicle use time band/road grade

Use Frequency (two times a day)		Use Time and Road Grade		
Vehicle Status Before Use: Cold Start		Morning	Evening	Night
Scenario 1	Residence Area Elevation Higher than Workplace	Descending	-	Ascending
Scenario 2	Residence and Workplace Areas at Same Elevation	Level	-	Level
Scenario 3	Residence Area Elevation Lower than Workplace	Ascending	-	Descending

Use Frequency (three times a day)		Use Time and Road Grade		
Vehicle Status Before Use: Cold Start, Third Time Hot Start		Morning	Evening	Night
Scenario 4	Residence Area Elevation Higher than Workplace	Descending	Level	Ascending
Scenario 5	Residence and Workplace Areas at Same Elevation	Level	Level	Level
Scenario 6	Residence Area Elevation Lower than Workplace	Ascending	Level	Descending

Scenarios 1 to 3 assumed two times a day use solely for commuting to work and returning home. Scenarios 4 to 6 assumed three times a day use of the vehicle, including once for another purpose before returning home. Scenarios 1 and 4 were cases where the residence area was at a higher elevation than the work place; this relation was reversed in Scenarios 3 and 6, whereas Scenarios 2 and 5 were cases without road grade.

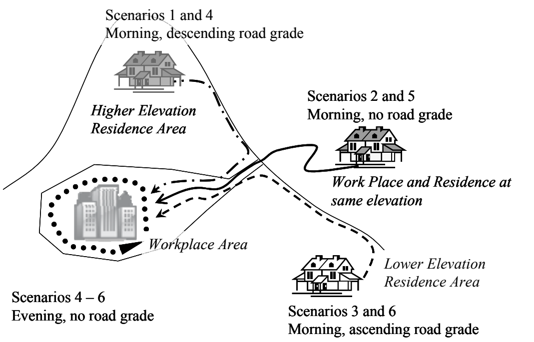

Fig. 3 Images of commuting to and from residence to workplace

Table 4 Auxiliary equipment use by period of vehicle use

Season	Morning	Evening	Night
Spring, Autumn			Headlights
Summer		A/C	A/C
Winter	A/C	A/C	Headlights, A/C

A/C = air conditioner

3 Results and Discussion

3.1 ICEV Base Case Performance

Table 5 shows the ICEV performance test results with cold start without road grade as the performance base case. Headlight use increased emissions of CO_2 to 1.08 times, CO to 1.04 times, and NO_x to 1.54 times the base case. Air conditioner use increased emissions of CO_2 to 1.21 times, CO to 1.57 times, and NOx to 1.25 times the base case. The results for warm start without road grade decreased CO_2 emissions to 0.86 times, CO to 0.16 times and NO_x to 0.39 times the base case.

Table 5 Ratio of ICEV emission coefficients for other cases to no road grade, cold start case (base case)

		Road grade [degree(%)]							
		0 (0%)				-2 (-3.5%)		2 (3.5%)	
		Cold	Ratio as Cold(0%) = 1						
		(g/km)	Hot	Headlights	A/C	Cold	Hot	Cold	Hot
Gases	CO_2	155.1	0.86	1.08	1.21	0.61	0.53	1.56	1.38
	CO	0.570	0.16	1.04	1.57	0.46	0.18	2.39	0.69
	NOx	0.015	0.39	1.54	1.25	1.85	0.36	1.36	0.24

Next, when a 2-degree positive road grade was added to running resistance, emissions of CO_2 increased to 1.6 times, CO to about 2.4 times, and NO_x to 1.4 times the base case. Conversely, for the case of a 2-degree negative road grade, emissions of CO_2 decreased to 0.61 times and CO to 0.47 times the base case, while NO_x increased to 1.9 times the base case. Although the percentage of change was great, the absolute amount of NO_x emissions was extremely small.

Although a test was not conducted for simultaneous use of headlights and air conditioning, for the discussions below, it was assumed that the emissions would be the same as that for use of air conditioning.

3.2 EV Fundamental Performance

Table 6 shows the results for EV performance with cold start without road grade as the performance base case. If an EV with 16-kWh battery capacity is considered as an example, the base case electric power consumption without road grade is 0.16 kWh/km. Calculations showed that use of headlights increased electric power consumption by 7.8% (0.012 kWh/km) whereas air conditioner use increased electric power consumption by about 34% (0.054 kWh/km). Converting to CO_2 emissions, use of headlights is equivalent to 6.9 g/km and air conditioning to 30.3 g/km. The impact of auxiliary equipment use increases for vehicles with lower battery capacity.

Next, electric power consumption for a –2-degree road grade was about one third (0.06 kWh/km) and for a +2-degree road grade about 2 times (0.32 kWh/km) the base case. Compared to the CO_2 emissions of 87.9 g/km for running with no road grade, CO_2 emission for running with the negative road grade were 32.2 g/km and 167.8 g/km for running on the positive road grade. The difference in CO_2 emissions between the base case of no road grade and 2-degree road grades ranged from –55.7 g/km to 79.9 g/km.

For air pollutants, NO_x emission for the base case were 0.034 g/km and the impacts of road grade on changes in emission were similar to those for CO_2.

Table 6 Effects of auxiliary equipment use and road grade burden on EV energy consumption

		Road grade [degree(%)]							
		0 (0%)				-2 (-3.5%)		2 (3.5%)	
		Cold	Ratio as Cold(0%) = 1						
Car	Unit	(base case)	Hot	Headlights	A/C	Cold	Hot	Cold	Hot
V24kWh	kWh/km	0.17	0.78	1.073	1.32	0.37	0.28	1.91	1.48
V16kWh		0.16		1.078	1.34				
V9kWh		0.15		1.083	1.37				
V24kWh	gCO_2/km	94.1		1.073	1.32				
V16kWh		87.9		1.078	1.34				
V9kWh		82.5		1.083	1.37				
V24kWh	gNO_x/km	0.034		1.073	1.32				
V16kWh		0.031		1.078	1.34				
V9kWh		0.029		1.083	1.37				

3.3 Comparison of the Environmental Burden of ICEV and EV

Comparison of the base case performances for substitution of ICEV by EV showed that, CO_2 emission decreased by 67.2 g/km while CO emission decreased by the total ICEV emission of 0.57 g/km. As NO_x emission for EV was greater, the emission increased by 0.016 g/km.

Compared to the base case for ICEV, use of auxiliary equipment increased emissions by 1.08~1.21 times for CO_2, 1.04~1.57 times for CO and 1.54~1.25 times for NO_x. Although EV do not emit CO, the increase in electric power consumption for auxiliary equipment use increased CO_2 and NO_x emissions by 1.07~1.37 times.

If the increases in CO_2 emission (g/km) due to auxiliary equipment use for ICEV and EV are compared, use of headlights increased emissions by 33.8 g/km for ICEV and 27.8 g/km for EV. Use of air conditioning increased emissions by 54.0 g/km for ICEV and 51.2 g/km for EV. The impact was lower in both cases for EV.

For ICEV, the effect of the ±2-degree road grades compared to the base case were changes in emissions of 0.61~1.56 times for CO_2, 0.46~2.39 times for CO and 1.85~1.36 times for NO_x. For EV, the changes in electric power consumption compared to the base case were –0.106 to 0.152 kWh/km. As a result, CO_2 and NO_x emissions changed by 0.37~1.91 times. Thus compared to base cases for the ICEV and EV, the changes in emissions due to road grade were –59.6 to 85.5 g/km for CO_2 and –0.02 to 0.03 g/km for NO_x. Taking road grade into account has a large impact on the effect of substituting ICEV by EV.

3.4 Use Assumptions on Effect of Substitution of ICEV by EV

The results for vehicle use frequency scenarios of two times a day for commuting to work and returning home are shown in Table 7. Only the data for the 16-kWh battery capacity case are shown for EV. As the simulation results for Scenarios 1 and 3 are the same, Scenarios 1 and 2 were compared. For the ICEV case, for Scenario 1 compared to Scenario 2, round trip emissions for CO_2 were about 10% higher (13.4 g/km) and NO_x emissions were about 60% higher (0.01 g/km). For EV, electric power consumption increased by about 14%, resulting in 11.7 g/km higher CO_2 and 0.005 g/km higher NO_x emissions. For conditions with road grade, substitution of ICEV by EV enabled a further 1.7 g/km reduction in CO_2 emission. However, NO_x emission increased slightly with substitution of ICEV by EV.

If the effect of auxiliary equipment use is added, ICEV emissions in Scenario 2 increased by 6.2~32.6 g/km for CO_2, 0.002~0.005 g/km for NO_x and 0.011~0.324 g/km for CO. ICEV emissions for Scenario 1 increased by 9.7~35.4 g/km for CO_2, 0.002~0.006 g/km for NO_x, and 0.027~0.462 g/km for CO. For EV, the electric power consumption for auxiliary equipment operation was added without regard to scenario, with emissions increasing by 3.5~33.7 g/km for CO_2 and 0.001~0.012 g/km for NO_x.

Although there were minor seasonal differences, switching to EV resulted in reduction of CO_2 emissions of 68 g/km for Scenario 2 and 73 g/km for Scenario 1. Emissions of CO were reduced by 0.57~0.89 g/km for Scenario 2 and 0.81~1.27 g/km for Scenario 1, with the reductions being about 40% greater for Scenario 1. For NO_x, emissions increased by 0.018 g/km for Scenario 2 and 0.012 g/km for Scenario 1. It should be noted that the NO_x emissions did not exceed the Japanese automobile emissions standard (0.05 g/km) [8]. Based on these results, it can be inferred that deployment of EV in areas with road grade would have effects comparable to those in areas without road grade.

The results for three times a day use are shown in Table 8. Compared to Scenario 5, the results for Scenario 4 ICEV emissions were 6.7 g/km higher for CO_2 and 0.004 g/km higher for NO_x, while CO emissions were 0.002 g/km lower. For Scenario 6 compared to Scenario 5, emission of all gases increased greatly (CO_2, 11.6 g/km; NO_x, 0.024 g/km; CO, 0.267 g/km). For cold start conditions with positive road grade, emissions during the morning use period are thought to have increased greatly. EV emissions increased slightly for CO_2 by 2 g/km and NO_x by 0.001 g/km for Scenario 4, and increased for CO_2 by 11.9 g/km and for NO_x by 0.004 g/km for Scenario 6. Compared to the no road grade CO_2 emissions (81.4 g/km), the 2-degree grade resulted in a 14% increase in CO_2 emission.

If auxiliary equipment effects are examined by season, compared to Scenario 5, ICEV CO_2

Table 7 Differences in ICEV and EV emission changes due to road grade (two times a day use)

		No auxiliary		Spring, Autumn		Summer		Winter	
		ICEV	V16kWh	ICEV	V16kWh	ICEV	V16kWh	ICEV	V16kWh
gCO_2/km	Scenario 2	155.1	87.9	161.3	91.4	171.4	103.0	187.7	121.6
	Scenario 1/3	168.5	99.6	178.2	103.1	193.9	114.8	203.9	133.3
gNO_x/km	Scenario 2	0.015	0.031	0.020	0.033	0.017	0.037	0.019	0.043
	Scenario 1/3	0.025	0.036	0.031	0.037	0.027	0.041	0.031	0.048
gCO/km	Scenario 2	0.570	-	0.581	-	0.732	-	0.894	-
	Scenario 1/3	0.810	-	0.837	-	1.198	-	1.272	-

Table 8 Differences in ICEV and EV emission changes due road grade (three times a day use)

		No auxiliary		Spring, Autumn		Summer		Winter	
		ICEV	V16kWh	ICEV	V16kWh	ICEV	V16kWh	ICEV	V16kWh
gCO_2/km	Scenario 5	148.0	81.4	151.5	83.7	168.2	101.6	179.1	113.9
	Scenario 4	154.7	83.4	160.4	85.7	180.5	103.5	187.2	115.9
	Scenario 6	159.6	93.3	161.7	95.6	176.1	113.5	193.1	125.9
gNO_x/km	Scenario 5	0.012	0.029	0.013	0.030	0.014	0.036	0.015	0.041
	Scenario 4	0.016	0.030	0.017	0.031	0.018	0.037	0.020	0.041
	Scenario 6	0.036	0.033	0.015	0.034	0.016	0.040	0.018	0.045
gCO/km	Scenario 5	0.410	-	0.411	-	0.535	-	0.643	-
	Scenario 4	0.408	-	0.413	-	0.591	-	0.640	-
	Scenario 6	0.677	-	0.678	-	0.805	-	1.063	-

emissions for Scenario 4 increased in the order of fall/spring, summer, and winter by 8.9, 12.3, and 8.1 g/km, respectively, while NO_x emission increased by 0.004 g/km. CO_2 emissions for Scenario 6 increased by 10.2, 7.9, and 14 g/km, respectively, while NO_x emission increased by 0.002 g/km. By substituting EV for ICEV, the average reduction in CO_2 emission for Scenario 4 was 73 g/km while the average increase in NO_x was 0.017 g/km. For Scenario 6, the average reduction in CO_2 emission was 65 g/km and the average increase in NO_x was 0.017 g/km. These results showed that for Scenario 4, where the home area was at a higher elevation than the work place area, the reduction in environmental burden for EV use was somewhat larger.

If the use of auxiliary equipment is considered, substitution of ICEV by EV results in increased reduction of CO_2 and CO while the emission of NO_x increase. Thus, at the present time, replacement by EV cannot reduce all of the environmental burdens. Reduction of the per unit energy NO_x emission by implementing power plant NO_x emission reduction measures will be required.

4 Conclusions

Based on assumptions of impacts of road grade on vehicle use and taking vehicle warm up status and auxiliary equipment use into account, the environmental impact of ICEV and EV were compared and the effectiveness of deploying EV in areas with elevation gradients was assessed. The JC08 mode was used as the driving cycle for chassis dynamometer tests conducted to investigate the effects on performance of auxiliary equipment use and road grade for ICEV while a driving simulation was used for EV.

The effects of auxiliary equipment and warm up status were confirmed to be about the same as those of road grade. In addition, as a result of substituting ICEV by EV, while CO_2 and CO emissions decreased, NO_x emissions increased for several cases.

Based on these results, realistic scenarios were set taking vehicle use frequency, auxiliary equipment use, and other factors into account to compare the relationship of residence and workplace areas to changes in CO_2 and air pollutant emissions. For cases when vehicle use was two times a day for morning and evening commuting, CO_2 reduction for substitution of ICEV by EV in an area with a 2-degree road grade was similar to that obtained for a level area. For cases assuming three times a day use, CO_2 reduction increased with road grade; and the reduction was shown to be larger when the residence area was higher in elevation than the workplace area. Although NO_x emissions increased slightly compared to level areas, promotion of EV deployment could be called worthwhile because CO_2 emissions reduction was larger than for level areas. However, reduction of NO_x emissions related to power generation will be important for reducing all of the environmental burdens associated with EV use.

Previous assessments of the effects of substitution of ICEV by EV have focused on CO_2 owing to a framework of measures to control global warming. However, as electric power generation emits air pollutants, comparison with air pollutant emissions by ICEV is required. The results of this research showed that NO_x emissions that accompany EV use were higher than for ICEV. In addition, there has been little previous consideration of the effects of auxiliary equipment use, road grade, and other factors on emissions of CO_2 and air pollutants. However, the results of this study have shown that a road grade of only 2-degree grade resulted in a 14% difference in emissions. Thus, evaluations of the effect of substituting ICEV by EV need to consider a wide range of factors.

Acknowledgments

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Authors

Dr of Eng., Yoshinori Kondo
National Institute for Environmental Studies, Japan
Tel: +81-29-850-2441
Fax: +81-29-850-2964
Email: kondos@nies.go.jp
Senior Researcher, Urban Atmospheric Environment Section, Center for Regional Environmental Research; Interests in EVs, electric or human-powered mobility, public transportation, and human health issues.

Dr of Eng., Hideki Kato
Toyota Transportation Research Institute, Japan
Tel: +81-565-31-8551
Fax: +81-565-31-9888
Email: kato@ttri.or.jp
Senior Researcher, Research Division; Interests in Ecodrive

MA of Ec., Yoshihiko Karakama
Association for the Promotion of Electric Vehicles, Japan
Tel:+81-3-5325-3365 Fax: +81-3-5325-3366
Email: Karakama@apev.jp
Senior Researcher; Interests in EVs, especially business model construction and market research for the diffusion.

Environmental Load Reduction of Substitution of Electric Vehicles by taking Geographical Features into account

YOSHINORI KONDO
Center for Regional Environmental Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
kondos@nies.go.jp

HIDEKI KATO
Toyota Transportation Research Institute, 1-1 Wakamiya cho, Toyota, Aichi 471-0026, Japan
kato@ttri.or.jp

YOSHIHIKO KARAKAMA
Association for the Promotion of Electric Vehicles, 6-10-1, Nishishinjuku, Shinjuku-ku, Tokyo 160-0023, Japan
karakama@apev.jp

1.Introduction

From the examination of substitution potential of electric vehicles (EVs) using long-term travel activity data collected in Tsukuba-city in Japan in around 2007, EVs were found to be replaceable for most passenger vehicles, if consumers will accept alternatives in less than 7% irregular conditions[1]. From the trip data of 2005 Road Traffic Census Survey, the substitution potential of EVs within the current passenger vehicle demand have been estimated by several researchers[2].

These estimations focused on daily travel distance. Geographical features such as road grade or difference of elevation between origin and destination of a trip were not taken into account. At present carbon dioxide emission is main issue on environmental burdens related to a vehicle. However, air pollutants from automobiles have not been solved yet. It is necessary to include the contribution of EVs to the reduction of air pollutants in comparison with internal combustion engine vehicles (ICEVs).

Our purpose of this study is to compare environmental burden of EVs to that of ICEVs by taking both geographical features and air pollutants when using an ICEV into account.

2.Research Method

Table 1 shows vehicle specifications for an ICEV and three types of EVs whose difference is battery capacity and weight. First, the chassis dynamometer test for an ICEV with JC08 driving cycle was carried out, where taking start condition and road grade of 0%, -3.5% and +3.5% into consideration.

As for an EV, running energy of a car was calculated as a basis of automotive engineering from both vehicle specification and sec-by-sec speed pattern data in the JC08 mode driving cycle by Japan government[3]. The efficiency at drive-train was supposed to vary from 0.7 to 0.9 in the simulation but it was constant during the driving cycle. It is also assumed that EVs' performance are not affected by start condition. EVs do not emit any emission when they were used. However, power plants emit air pollutants to produce the electricity. To compare the environmental burden of ICEVs with that of EVs, the emissions of CO_2 and NOx at power plants are included in the evaluation.

3.Results and Discussion

Chassis dynamometer test results

Emission amounts of exhaust gases when traveling 8.2km by JC08 were shown in the upper part of Table 2. The CO emission was highly different by road grade and by start condition, while NOx emission showed relatively small difference.

Numerical simulation results

The lower part of Table 2 was the result calculated by numerical simulation. For example, V16kWh required 0.122kWh/km to drive 8.2km at 0% road grade, where efficiency at drive-train is 0.9 and 0.157kWh/kg in case of efficiency of 0.7. The resultant CO_2 emission was 87.9g/km using Japanese average CO_2 emission factor of 561g/kWh, and minimum CO_2 emission was 43.3 g using 355gCO_2/kWh that is the lowest among electric power companies in Japan[4]. The NOx emission varied from 0.024 to 0.031g/km at 8.2km driving with the emission factor of 0.2gNOx/kWh[5].

Environmental loads by an ICEV and an EV

Comparing these values with those of ICEVs, it was found that CO_2 emission was reduced in almost all cases but NOx emission was increased in some cases rather than decreased.

Supposing the vehicle moved to a 8.2km far place with an inclination of 3.5% and come back with an inclination of -3.5% (case1) and no inclinations (case2). The CO_2 emissions for cold start condition by an ICEV were 242+94.9=336.9g/km in case1, while CO_2 was 155.1*2=310.2g/km in case2. As for a V24kWh EV, CO_2 emissions were 213.9g/km in case1 and 188.1g/km in case2, respectively. CO_2 reduction amounts from an ICEV to a V24kWh EV accounted for 123g/km in case1 and 122g/km in case2. On the other hand, NOx emissions increased 0.026g/km in case1 and 0.036g/km in case2.

The reduction amounts of emissions for hot start showed the similar to those for cold start. The CO_2 decreased around 122g/km while NOx emission increased around 0.03g/km. In this range of road grade, the effects by taking road grade into account were small. That is, substitution of EVs is suitable for a place with some inclination for cold start from the viewpoint of reduction of environmental burden.

4.Conclusion

Environmental burdens of EVs was compared with those of an ICEV by taking both road grade and air pollutants emitted by an ICEV into account. It was found that CO_2 emission was reduced but NOx emission was increased in many cases rather than decreased. From the comparison of environmental loads between ICEV and EVs, substitution of EVs is suitable for a place with some inclination for cold start condition.

Table 1 Vehicle specifications

Items	Unit	Electric Vehicles V24kWh	V16kWh	V9kWh	ICEV
Vehicle weight	kg	1,333	1,219	1,119	990
Battery capacity	kWh	24	16	9	-
Dimension	mm	W1695xH1475			
Frictional resistance : μ		0.011			
Coefficient of air resistance : Cd		0.395			

Table 2. Comparison of emissions when we travel 8.2km (JC08mode driving cycle) by internal combustion engine vehicle (ICEV) or electric vehicles (EVs) where climbing up or down a hill

				Road grade					
				-2 degree(-3.5%)		0 degree(0%)		2 degree(3.5%)	
				Vehicle condition					
Vehicles	Items		Unit	HOT	COLD	HOT	COLD	HOT	COLD
ICEV	Gases emissions	CO	g/km	0.102	0.260	0.090	0.570	0.393	1.360
		NOx	g/km	0.006	0.029	0.006	0.015	0.004	0.021
		CO_2	g/km	81.6	94.9	133.7	155.1	214.0	242.0
	Fuel consumption		L/km	0.035	0.041	0.058	0.067	0.092	0.104

				Efficiency at drivetrain					
				0.9	0.7	0.9	0.7	0.9	0.7
EV	V24kWh	Electricity consumption	kWh/km	0.05	0.06	0.13	0.17	0.25	0.32
	V16kWh			0.04	0.06	0.12	0.16	0.23	0.30
	V9kWh			0.04	0.05	0.11	0.15	0.22	0.28
	V24kWh	CO_2 emission	g/km	26.8	34.4	73.2	94.1	139.6	179.5
	V16kWh			25.2	32.4	68.4	87.9	129.8	166.9
	V9kWh			23.8	30.6	64.2	82.5	121.2	155.8
	V24kWh	NOx emission	g/km	0.010	0.012	0.026	0.034	0.050	0.064
	V16kWh			0.009	0.012	0.024	0.031	0.046	0.059
	V9kWh			0.008	0.011	0.023	0.029	0.043	0.056

CO2 emission factor (EF) = 561g/kWh[4], EF for NOx = 0.2g/kWh[5]

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