

# Development of Greenhouse Gas Estimation Method for a Local Government Level Using Traffic Demand Model

Pennie Rose Anne R. Maurillo\*

정현지\*\*  
(Hyeon-ji Jung)

이선하\*\*\*  
(Seon-ha Lee)

하동익\*\*\*\*  
(Dong-ik Ha)

## 요약

현재 온실가스 배출량 산정 방법은 온실가스 저감대책 효과 분석이 불가능하며 차량의 이동특성이 반영이 안 된 실정으로 이를 극복할 수 있는 온실가스 배출량 산정 방법의 필요로 본 연구가 시작되었다. 교통수요 분석을 통해 차종, 교통상황에 따른 HBEFA 배출계수로 배출량을 산정하는 방법을 통해 고양시에 적용하여 분석하였다. 본연구의 지자체단위 교통수요 추정방안을 통해 실질적인 교통 이용특성에 맞는 온실가스 배출량이 산출되었다. 온실가스 지자체별 통행요금, 속도제한 등 온실가스 저감 요인들이 교통수요 모형에 반영되어 온실가스 저감 대책에 대한 효과분석 후 환경영향을 줄일 수 있는 방안을 강구하여 온실가스 저감 대책 마련에 효율적으로 이용될 것으로 판단된다.

핵심어 : 온실가스, 도로교통 배기오염, 교통수요, 온실가스 저감 효과분석, 지구온난화, 거시적 교통분석

## Abstract

Greenhouse gas emissions have been an important issue in different countries because of their effects on global warming. The government has to organize greenhouse gas reduction measures suitable to regional characteristics by establishing annual implementation plans and comprehensive policies based on the UNFCCC. The transportation sector is one of the major contributors of air pollution; hence increasing need to estimate current and future traffic emissions precisely. Under these circumstances, a number of emission models have been developed recently. However, current methods of estimation cannot carry out effective analyses because it does not reflect vehicle movement characteristics. This study aims to present a new method for calculating road traffic emissions in Goyang city. A travel demand model is utilized to carry out GHG emission estimates according the traffic data (fleet composition, vehicle kilometers travelled, traffic intensity, road type, emission factors and speed). This study evaluates two approaches to estimate the road traffic emissions in Goyang City: Pollution-Emis and the Handbook of Emission Factors for Road Transport (HBEFA v.3.1) which is representative of the "average speed" and the "traffic situation" model types. The evaluation of results shows that the proposed emission estimation method may be a good practice if vigilant implementation of model inputs is observed.

**Keywords:** GHG emission inventory, emission model, travel demand model, road traffic

\* 주저자 : 공주대학교 교통공학과 석사과정

\*\* 공저자 및 교신저자 : 국토연구원 국토인프라 연구본부 연구원

\*\*\* 공저자 : 공주대학교 건설환경공학부 도시·교통공학 교수

\*\*\*\* 공저자 : 서울대학교 건설환경종합연구소 연구교수

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## I. Introduction

The industrial revolution has brought rapid increase in fossil energy consumption. The transportation sector represents the highest growth in emissions in all sectors which accounts for all significant environmental impacts like climate change (IEA,2012). The United Nations Framework Convention on Climate Change (UNFCCC) in cooperation with different countries has put best efforts to support all necessary undertakings to prevent global warming by reduction of GHGs. Estimation of road traffic emissions and fuel consumption is becoming necessary for the evaluation of environmental policies.

Korea's rapid economic growth for the past decades have ensued growing pressure on the environment due to increased energy consumption. The country's living standards and extremely fast expansion have made it one of the most rigorous economies in the OECD area. Environmental impacts have been one of the negative attributes of urbanization. According to the report from the Korea Energy Economics Institute, the total net greenhouse gas emissions in Korea is 182.1 Mt in 2009, this denotes 142.4% increase compared to 1990. CO<sub>2</sub> was responsible for the highest proportion of green house gas emitted in 2009 which is about 89% of the total emissions which was the result of the country's heavy dependence on oil and gas followed by CH<sub>4</sub> (4.6%), SF<sub>6</sub> (3.1%), N<sub>2</sub>O (2.1%), HFCs (1.0%) and PFCs (0.4%). The transportation sector accounted the largest increase in energy consumption, representing a ten-fold escalation from 1980-2009. The road transportation comprised 79.1% of transport energy consumption in 2007. Road transport is the highest contributor to GHG emissions since it is the most convenient mode of transportation. (Singh,2008)

Although fuel specifications and end-of-pipe technologies have decreased the emissions per kilometer of some pollutants, increased travel demand

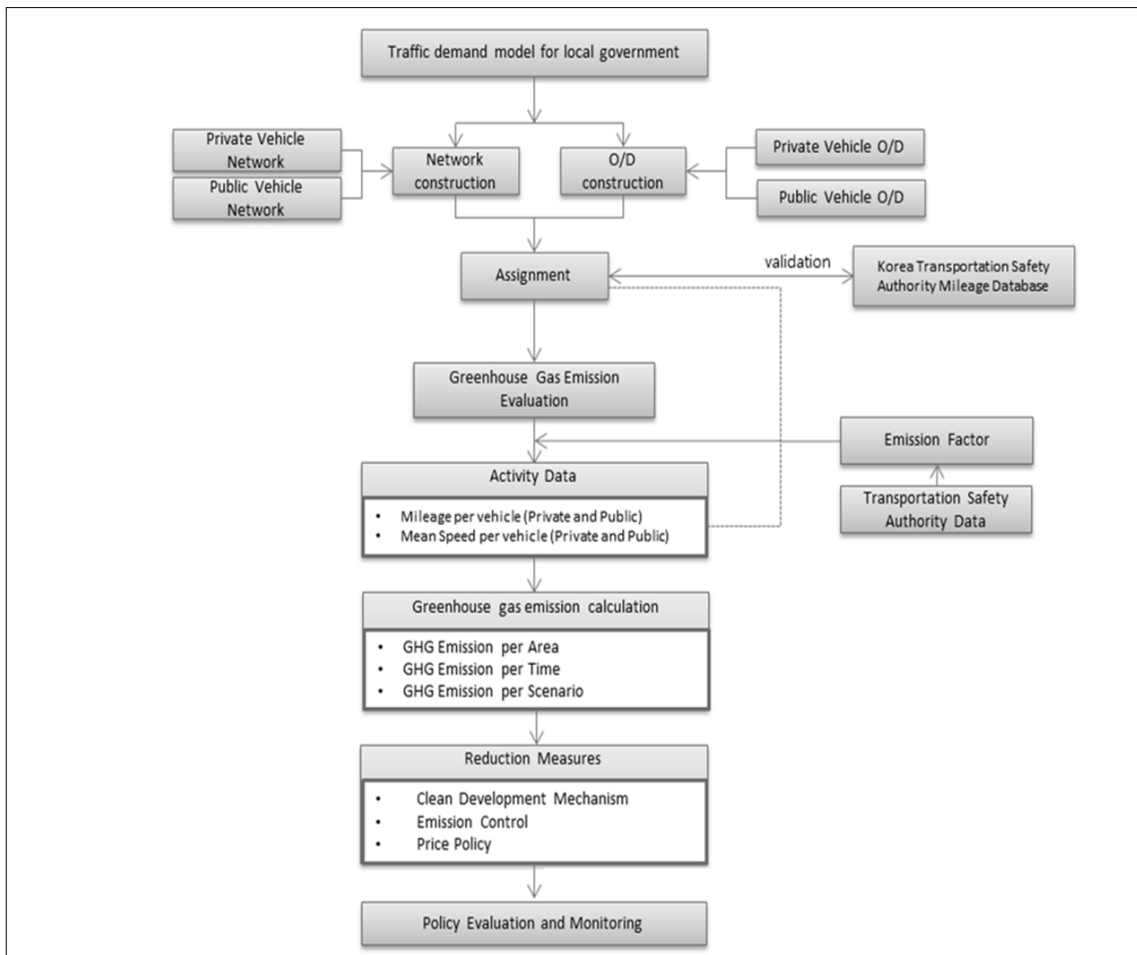
and congestion have sternly offset the beneficial effect on air quality. In the past years, different real-time traffic policy measures have been developed to manage travel demand and influence driver behavior. According to (Chiquetto, 1997) although traffic demands were primarily designed for network efficiency improvement and to reduce congestion, they also have significant effects on urban traffic pollution. Different types of traffic data were essential in the emission modeling process like vehicle volume, fleet composition, average speed and infrastructure characteristics (road type, length, speed limit, number of lanes). Traffic models were frequently used to generate the required traffic data to input to emission models. The process to generate traffic data however increases with the road network size (Smit et al., 2008). Traffic models usually generate macroscopic traffic data for each road link in a large urban network. Macroscopic simulation models based on average speed have been the most common methodology for estimating road emissions for the past years. In Europe, most inventories for exhaust emissions for a city are still calculated using average speed model like Copert IV (Panis et al, 2006). According to (Andre and Hammarstrom, 2000) average speed is also an important variable in emission modeling because traffic emissions were clearly dependent on speed in a non-linear manner. Inaccurate speed predictions may strongly affect emission estimation. Given that emission modeling is sensitive to speed, improvement on estimates of mean link speed from static macroscopic traffic models using traffic data that is relatively easy to obtain by considering Emission Specific Characteristics (ESC). (Nesamani et al., 2006)

This study proposed a traffic demand-based model in calculating the greenhouse gas emission for the local government in Korea. The results of traffic assignment (average speed and mileage per facility

type) from the travel demand forecast serve as input to the emission model that calculates the total emissions for the transportation network. The required traffic data for the emission models was generated using Visum Public Transit software. Visum was also equipped with environmental impact calculation utilizing the Pollution-emission and the HBEFA. The next section of this paper presents the proposed methodology to estimate emission, discussion of the results based on local government traffic demand and technique validation for GHG emission estimation. The last section concludes the paper.

## II. Methodology

The greenhouse gas emission inventory for the road sector for local government was calculated using a macroscopic traffic simulation. A transport model was developed through network construction and O/D construction. The analysis methodology for obtaining greenhouse gas emission inventories was presented through a flowchart shown in Fig. 1.



〈Fig. 1〉 Analysis methodology flowchart for greenhouse gas emission computation

## 1. Traffic models

To generate the required traffic data for emission models, different traffic models were utilized. Considerable efforts have been dedicated to develop models to describe road emissions and air pollution resulting from the employment of policy measures in real-life traffic (Int Panis et al., 2005). In practice, means to generate and process traffic data also increases with the road network size. The detail of traffic data is reduced as the road network increases. Macroscopic traffic models were designed to generate traffic data for each road link in the network for large urban road networks. (Brindle et al., 2000) These macroscopic models require enormous simplifications on the accuracy of physical processes involved in pollutant emission. The main source of information used to feed both Pollution-Emis and HBEFA was the traffic demand model of the municipality of Goyang. VISUM ver.12 is a macroscopic simulation model for equilibrium traffic assignment supported by a Geographic Information System (GIS) where the road network of the city of Goyang is represented by 14,378 links. Imperative to the accuracy of traffic simulation is the quality of the actual modeling of the network and the demand model. VISUM has the ability to create an environmental impact model based on the input data provided by network and demand model (PTV AG, 2011). The demand model in VISUM deals with the traffic conditions which has the ability to forecast travels by analyzing daily travel behavior of people. It is important for the network and demand models to carry out precise data to be able to present reliable results. Traffic flows and average hourly speeds were obtainable at link level while fleet compositions were estimated at management area level. The traffic flow statistics was day-specific and vehicle-specific. This allows each vehicle's temporal activity pattern to be monitored which is an important

factor in determining the air quality and the emissions in the system (Lindhejm et al., 2012).

### 1) Network model

The study network is located in Goyang City, South Korea. Building a network map for traffic demand model is divided in four major steps. The model includes the road infrastructure with all the traffic and spatial structure that represents the actual situation of the transport source.

1. The zone building is based on the KTDB (Korea Transport Database), the traffic zone radius for Goyang city was set to 10.6 km radius to account for the direct and indirect influences on the transport system affecting the city.
2. For the characterization of the links, we have used the Navigation network instead of the KTDB network.
3. The local government in Korea has set the standards per node and link, but because we have utilized the navigation network link, we have to build a nodes and links suitable for the network.
4. The road network of the Goyang city study is presented in Fig. 2. Inside the area shows selected macro transport zones which are potential origin and destination points. According to a study by (Kang et al., 2012) the network should be divided into management areas in order to provide a variety of assignments. To allocate the traffic patterns in Goyang City, we divided the area in 314 zones.
5. The Volume Delay Function (VDF) was also utilized with reference to the set information to account for the impedances of network objects. The Korea Development Institute has set VDF parameters ( $\alpha$ ,  $\beta$ ) to be allocated for each network object type.



〈Fig. 2〉 Goyang city model generated in VISUM

## 2) Origin and Destination and Assignment

The O/D in Goyang City was built according to individual behavior models taking into account the characteristics of traffic data needed for the analysis. A household survey data was conducted to account for the actual trips made in the project study area. The household passage survey was performed in 2010 according to the effective sample rate of about 2.4% to 3.6% for the total population in the town and zones. In this study we considered 2.2% of the total number of households (360, 212 households) and 2.4% of the total population (950,115 persons) for the survey data. Simulation techniques are most commonly used because of difficulties in obtaining both forecast values and actual values in the forecasting process. (Sanko et al., 2013) presented evaluation of uncertainties about forecasting models. In simulation studies they have pointed out that input uncertainties are more common than model uncertainties. In this study O/D was built based on individual behavior models. This was conducted by analyzing transient traffic patterns of individual groups per household. This method made data collection difficult to obtain for a short time but is a low cost alternative traffic plan rating possible benefits. The model used in this study is defined by individual behavior models of

socio-demographic indicators considering the effects of transport policy and traffic patterns with similar population groups. Demand matrices were partially determined by surveys and mathematical models were used to reproduce the demand ratios. Mode choice and traffic distribution phase occurs after the passage of total travel demand was distributed to a variety of transportation models. The demand model has a behavior-oriented concept which characterizes the decision-making aspect of the road users. This was illustrated in a discrete distribution model (Logit model) which specifies the probability of selecting a particular destination zone based on the number of trip attractions in all possible destination zones presented in Eq. 1. The total O/D matrix generated from all modes and group generated by the model in Goyang City was presented in (Fig. 2). The matrix contains the sum of the walk, car passage, train, bus, taxi demand created in all the zones. The assignment is the last step in the modeling process, which is based on the OD matrix, network description and speed flow functions. The result of the assignment (total link flow and VMT) is the basis for validating the model and evaluating the environmental impact. This study used the Equilibrium assignment which distributes the demand based on Wardrop's first principle of route choice. The equilibrium assignment determines a user optimum and a system optimum. A user optimum means that no user will profit from any changing path when the system is in equilibrium (Wardrop, J., 1952). The system optimum on the other hand minimizes the total impedance in the network for all the OD pairs which lead to shorter journey time per road user. Equilibrium traffic assignment and measured data were compared. The measured data was based on the observation of National highways and routes provided by the Traffic information system. To ensure that the traffic assignment is reflective of the real traffic situation a demand calibration should be performed

using TFlow Fuzzy. Tflow Fuzzy is a matrix correction method for the OD Matrices so that the results of the model transportation supply can match the observed traffic supply. Once the Tflow fuzzy was run for each demand segment, all the matrices were reassigned on the network and changes were made by using projection routes approach which is available in VISUM. The total demand matrix is presented in fig. 3

$$P_{ij}(m) = \frac{e^{U_{ij}(m)}}{\sum_{k=1}^m e^{U_{ij}(k)}} \quad \text{Equation(1)}$$

$i, j$  = traffic zone

$m$  = index of modes, (M= total no. of modes)

$P_{ij}(m)$  = probability of selecting mode m for trip i to j.

$U_{ij}(m)$  = value of utility between zones, utility of selecting m for trip i to j.

Zones	150	151	152	153	154	155	156	157	158	159	160	
150	0	3091.44	2472.00	580.74	125.28	866.72	401.83	132.21	278.91	315.46	844.41	729.91
151	1287.87	0	922.94	760.20	47.99	399.23	163.63	81.33	239.29	62.55	1128.84	628.16
152	693.66	125.48	0	49.57	208.75	198.96	81.76	25.87	46.59	88.62	129.30	123.96
153	391.82	862.44	464.43	0	197.54	1348.11	1713.64	236.99	427.27	903.05	1024.50	843.45
154	17445.43	399.66	164.10	81.17	1814.98	1437.43	85.63	161.85	186.95	365.59	315.09	
155	5886.19	135.51	59.63	36.02	242.08	84.42	742.15	97.01	85.51	245.73	172.47	
156	9683.89	275.03	197.52	47.11	420.91	191.61	96.45	1308.45	85.20	789.43	395.88	
157	11762.83	300.10	50.33	88.51	479.91	171.03	84.85	89.90	1149.88	274.35	179.44	
158	39879.85	861.26	1295.70	132.30	1045.97	398.12	250.40	848.63	264.47	8952.30	1663.94	
159	36794.52	752.46	899.41	126.60	854.62	388.47	175.51	412.41	168.02	1642.72	8881.05	
160	27738.91	482.28	275.28	99.77	613.57	246.42	88.71	103.57	190.26	448.24	391.45	
161	67412.22	1185.90	629.88	437.20	1761.20	729.13	261.84	263.52	999.91	1467.26	1286.87	
162	85261.12	1979.90	788.96	592.28	3429.37	1122.45	362.04	879.87	896.66	2285.85	1897.70	
163	39255.96	620.60	182.88	164.34	712.75	262.40	118.25	119.92	195.40	959.67	491.83	
164	38446.71	752.03	398.63	214.77	989.50	422.02	136.02	146.43	375.54	790.53	596.10	
165	58888.67	841.04	288.27	359.29	1382.70	577.87	217.52	296.79	625.67	980.32	789.73	
166	53311.29	711.67	184.26	215.13	1305.02	628.92	130.31	217.41	401.50	1249.95	1030.88	
167	10596.72	189.54	34.29	50.89	220.18	85.92	44.85	45.91	52.64	184.87	178.84	
168	65554.28	1099.68	395.67	388.81	1937.66	683.72	202.56	304.53	795.93	1070.69	839.88	

(Fig. 3) Total demand matrix for Goyang city

## 2. Emission factors

In current practice it is assumed that all vehicle activity is the same regardless of the variation of traffic and driving characteristics. Different emission rates are based on average speed and assumed urban driving cycle which may not be able to represent real-world driving patterns. The HBEFA and the Pollution-Emis included different driving patterns

based on facility type, LOS which is more similar to real-world profiles in terms of average speed and acceleration; however the accuracy of these models still relies on the network activity data from the travel demand model which are still based on steady state (static) analyses.

### 1) Pollution-Emis

The reference model for calculating the greenhouse gas emission from the traffic demand model generated in VISUM was the HBEFA 3.1 and the Pollution-Emis. Although the Ministry of Land and Transportation in Korea has provided a list of emission factors for the road transportation sector, we still this study still used the emission factors provided by the HBEFA and Pollution-Emis because of the absence of some pollutants relevant to the calculation of the total GHG estimate (e.g N2O and CH4). The Pollution-Emis was based on the emission factors for the pollutants such as NOx, CO, HC and SO2 which was set by the Swiss Federal Office for the Environment. This air pollution analysis model functions to calculate the emission per vehicle type for both cars and HGVs (trucks). (Chang et al., 1981 ) presented the detailed derivation of emission factor E and the total emission Etot . The emission factor per vehicle fleet is calculated by the equation 2. Wherein Etot is the combined emission for both LDV and HDV and N is the total number of vehicles passing by a certain time interval.

$$E = E_{tot} / N \quad \text{Equation(2)}$$

$E$  = emission

$E_{tot}$  = total emission

Pollution-Emis procedure in VISUM is average speed centered which means that the calculations rely

on speed equations, which are characteristic of a given vehicle type. Due to the dependence of the LDV and HDV emissions on speed, (Kirstensson et al., 2004) suggested to improve the estimation of emission by fitting the emission factors in a third degree polynomial. In the Pollution-Emis procedure, the parameters were fitted in a 5<sup>th</sup> degree polynomial to obtain the emission factors for each pollutant shown in eq.3. Since macroscopic models usually generate traffic data for two major vehicle classes only, (LDV and

HDV), emission were developed using fleet composition for Goyang. The input parameters for the flexible emission formulas for different pollutants are given in table1.

$$E = a + bv + cv^2 + dv^3 + ev^4 + fv^5 \quad \text{Equation(3)}$$

$E$  = emission

$V$  = speed of LDV and HGV

<Table 1> Flexible emission formulas, Swiss federal office for the environment

Pollution	NOx		CO		HC		SO	
	LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV
a	0.18965	18.059	3.2587	45.38	0.43608	46.49	117	1980.4
b	5.58E-03	-0.60349	-8.05E-02	-3.0729	-1.34E-02	-3.7859	-3.89E+00	-87.564
c	-1.93E-04	1.66E-02	6.73E-04	9.79E-02	1.86E-04	0.13382	7.28E-02	2.912
d	2.57E-06	-2.30E-04	-1.21E-06	-1.61E-03	-1.22E-06	-2.32E-03	-7.24E-04	-5.07E-02
e	-6.56E-09	1.66E-06	-6.39E-09	1.31E-05	3.97E-09	1.93E-05	3.89E-06	4.33E-04
f	-2.07E-11	-4.13E-09	3.77E-11	-4.14E-08	-5.66E-12	-6.14E-08	-8.20E-09	-1.36E-06

Source: Emis2000.DAT

<Table 2> HBEFA classification for emission factor

Vehicle Categories	Vehicle Size	Fuel Type	Emission Standards	Reduction Technologies
Passenger Car	PC < 1.4 L	Gasoline	Pre Euro 1	Particle Filter
Motorcycle	PC 1.4 - 2.0 L	Diesel	Euro 1	SCR
Urban Bus	PC > 2.0 L	LPG	Euro 2	EGR
Coaches		CNG	Euro 3	
Light duty vehicle	Truck ≤ 7.5 t	FFV	Euro 4	
Single Truck	Truck 7.5 - 12 t		Euro 5	
Truck Trailer	Truck 12- 14 t		Euro 6	

Abbreviations:

PC = Passenger Car ; LPG = Liquefied Petroleum Gas;

CNG = Compressed Natural Gas; FFV Flexible Fuel Vehicles

SCR = Selective Catalytic Reduction; EGR = Exhaust Gas Recirculation

## 2) HBEFA

An alternative calculation approach is the HBEFA 2.1 which was established on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria supported by different countries as well as the European Research Center of the European Commission (Haan & Keller, 2000). HBEFA serves as the most comprehensive road traffic emission model since it presents numerous number of traffic situation defined by the area, road type, speed limit and service level parameters. Consequently, proper characterization of the traffic situations that actually occur must be made for every link during the day. Each link was assigned to a particular road type considering characteristics such as road capacity, number of lanes, and free flow speed. VISUM utilized the basic approach for calculating emissions from the product of the traffic volume and the emission factors. The emission calculated is the total mass of each pollutant emitted by the vehicles on the network link at a specified time interval. The speed limit representing the flow speed of the traffic model was assigned to each link after defining each road link type. Traffic situation parameters are defined by the HBEFA for the easy application of the emission factors. The handbook on emission factors for road transport has classified the emission factors for different vehicle sub segments as shown in Table 2. A key feature of the HBEFA model is that it can define 256 different traffic situations categorized by the area (rural, urban), road type, road speed limit and level of service (free flow, heavy, saturated, and stop and go.) It is imperative to classify the road level of service according to the methodologies presented by the HBEFA. (Borge et al., 2012) presented the estimation of this critical parameter by using the ratio of average speed and speed limit. The emission model utilizes vehicle information such as fleet type and age. Fleet

characterization is suggested per country, per calendar year and per vehicle category (cars, HGV, etc.). Such information are necessary to estimation the emissions in each driving category. The emission factors are available in the Handbook Emission Factors for Road Transport by (de Haan and Keller, 2004). In this study, we utilized emission factors set by the HBEFA in order to characterize different traffic situations in Goyang city.

## III. Results

Air pollution quantities have been a major concern at local and regional level. The road transportation sector accounts for significant quantities of CO<sub>2</sub>, CO and NO<sub>x</sub> and minimal quantities of CH<sub>4</sub>, N<sub>2</sub>O and SO<sub>2</sub>. The dramatic increase of energy consumption in the transportation sector in Korean cities was accountable to the rise of car use and traffic congestion. Due to the high rates of vehicle ownership, the transportation sector is responsible to the 633% upsurge of energy consumption from 1980-2009 (Korea Energy Economics Institute, 2011). Green house gas emission calculations based on fuel statistics were common but yields to uncertainties due to varying technological factors and conditions. This section presents the emissions resulting from the application of the Pollution-Emis and the HBEFA in the modeling domain. Efforts have been made to reduce uncertainties in the estimation of emissions by addressing issues in the activity data like consideration of the mileage per vehicle, mean speed and considering service level of roads.

### 1. Greenhouse gas emissions

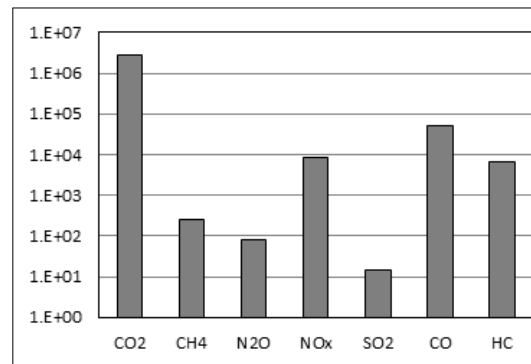
The results obtained from the HBEFA emission model for Goyang City were presented in Figure 4. The HBEFA emission model gives a more detailed



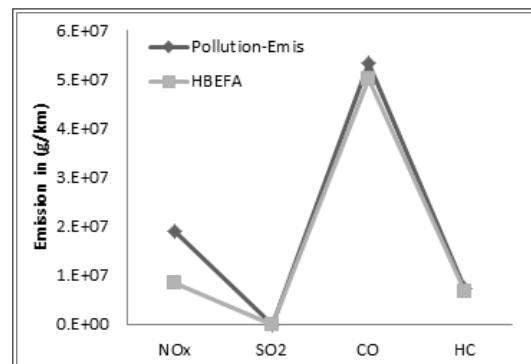
emission calculation considering various numbers of pollutants. The demand model was simulated on a time basis of one day. The total emissions generated in Goyang City were 0.003 Mt/day. The highest emission generated was CO<sub>2</sub> which was perceptibly denoted by the use of fossil fuels which were the primary energy source of the transportation sector. From the calculations we can infer that the total emissions of Goyang City 1.04 Mt/year. The total emissions on a daily basis were also calculated per area and per person which were 10660 kg/km<sup>2</sup> and 2.66kg/perperson. Although the pollutants estimated by the Pollution-Emis model are relatively few compared to the HBEFA, it was still important to assess the emissions obtained by the model because these pollutants were most eminent in the combustion process. In this case, we may compare the resulting emissions in terms of CO, SO<sub>2</sub>, NO<sub>x</sub> and HC which was presented in Figure 5. Generally, the resulting emissions obtained with the Pollution-Emis are higher than the HBEFA. The total emissions in the modeling domain are 79,593,817 and 65,047,814 grams respectively, the emissions from the Pollution-Emis is 22.4% higher than HBEFA. According to these estimates, NO<sub>x</sub> and SO<sub>2</sub> emissions from the Pollution-Emis model is 128% and 69% respectively which represent 71% of the total emissions from the HBEFA. Since the emission factors for the Pollution-Emis was from the year 2000 data, the researchers compared the more updated HBEFA model with the emission estimates from the State Transportation Sector Emission Report in 2010 by the Transportation Safety Institute. The CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions per day based on TSA were 4,279,755,342g/day, 1,434,066g/day and 31,268g/day (4.61x10<sup>-5</sup>Mt) respectively.

The total CO<sub>2</sub> emission estimated from TSA was 53% higher than the HBEFA. According to the TSA estimate, the CO<sub>2</sub> emissions from the road traffic

would exceed the sum of the total HBEFA emissions by 48%. The divergences in the emission estimates may be attributed mostly to the difference between the emission factors assigned to the traffic situations. In the Pollution-Emis model, emission factors were characterized by LDV and HGV per each pollutant, however the HBEFA emission factors were results of different vehicle categories ( e.g. PC-diesel- Euro 3, PC-Gas-Euro4 or BUS, Euro4). The large discrepancy in emission factors may be explained by the implicit consideration of different speeds or flow conditions.



(Fig. 4) Goyang city total emissions per day in g/km based on HBEFA emission model

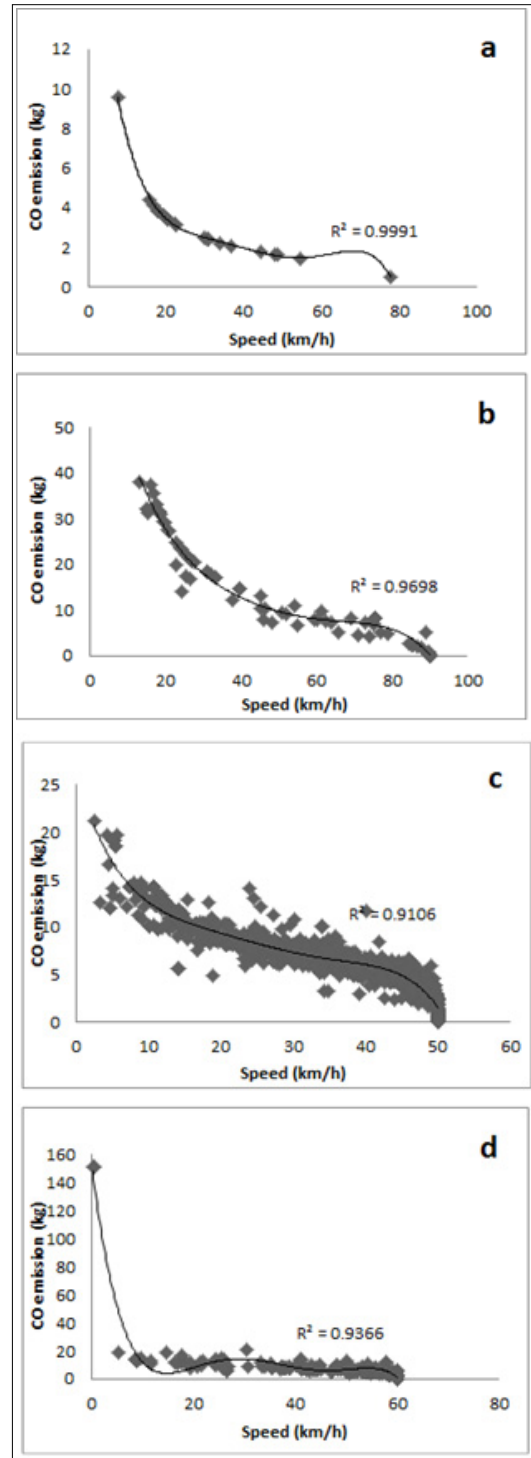


(Fig. 5) NO<sub>x</sub>, CO, SO<sub>2</sub> and HC emissions according to HBEFA and pollution-emis

## 2. Influence of average speed and volume

According to the methodology implemented in this

study, each link is associated to a traffic condition with corresponding emission factors. In most studies, average speed was a basis for the measurement of traffic performance. Emissions measured from most tunnel studies involved wide range of vehicles characterizing the on-road fleet, however the trends are comparable and depicted a strong speed influence (Andre et al., 2000). To show the influence of speed in the emission estimates, emission values were taken per link by representing the travel time spent on each link. The link speed was estimated by the travel demand model. The emission values generated were plotted against their average speed. Furthermore, different emission-speed curves specifically for CO pollutant were established for different links as shown in Figure 6. The regression curve depicts the relationship of the emissions and the vehicle activity. In the scatter plot, emissions were relatively high for very low average speed (10-30 km/h) and consequently low on moderate speed (60 to 90 km/h). It was also observed that the determination coefficient,  $r^2$ , for all the links were ranging from 0.9106 to 0.9991 which showed that the relationship of speed and emissions were very clear. It is implicit that the low average speed may generally represent stop and go driving or congestion, which means that vehicle movement in the link is infrequent hence higher emissions are recorded. Generally, the emission-speed curve when plotted forms distinctive parabolic shape, with high emission rate on both ends since higher speeds will also cause high emission rates. This is because higher speeds entail a greater fuel requirement which leads to higher emission rates. Through vehicle activities observed at link level, the average speed was computed in the model as equilibrium over the number of nodes connecting it. Therefore, it should be eminent that the obtained average speed in the model may represent the average speed concept in the urban driving cycle (Zachariadis and Samaras, 1997).



(Fig. 6) Emission-Speed curves established from different links

## IV. Case Study

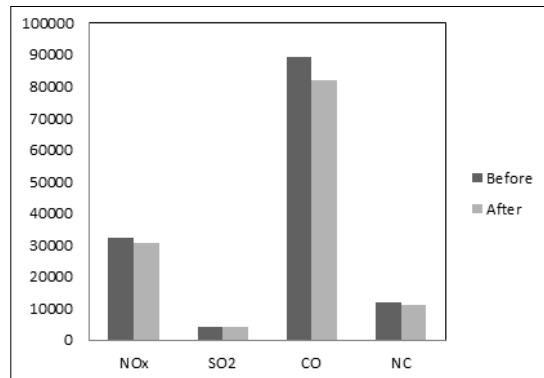
In compliance with the Kyoto Protocol to the UNFCCC (United Nations Framework Convention on Climate Change) to reduce greenhouse gas emissions in 2020, the Korean Government created a Low-Carbon Green Growth policy to cut national greenhouse gas emission to 30%. Reduction measures were applied to the traffic demand model and significant changes in the greenhouse gas emissions were noted.

### 1. Increase in toll and parking fees

Since cars have been the main mode of road transportation in Korea, reductions measures will be applied to inhibit car use. Two scenarios were applied by increasing the toll fare and increasing the parking fee, the effects were attributed to the demand model. Table 3 shows the effect of increasing the toll fare and parking fees would be a basis for the population to change their means of transportation. Differentiation of road tolls can induce perceptible changes in human behavior (Fiorello and Martino, 2009). In this study we assume a sample size of 10% of car users who would shift to a different mode of transportation when the increase of fees would be applied. Before implementing the two scenarios, the rate of car users is 37.56% and the rate of bus users is 30.45% and 31.98% is based on other mode of transportation. Upon implementation of the increase in fees, 3.75% car users shifted to utilizing the bus (Table 3). With the integration of the change in mode shares in the demand model, subsequent decrease in NO<sub>x</sub>, SO<sub>2</sub>, CO and HC emissions were observed in the results. Significant decrease in CO emissions was observed from 89,450 g to 81,911 g, while minimal changes in NO<sub>x</sub>, SO<sub>2</sub> and NC were also shown in Figure 7. The increase in fees would entail 7.071% average decrease on the greenhouse gas emissions.

〈Table 3〉 Change in vehicle share as a result of increase in parking in toll fees

Increase of in parking and toll fees			
	Before	After	Total Change in share
Car	37.56	33.81	-3.75
Bus	30.45	34.22	3.75
Others	31.98	31.98	0



〈Fig. 7〉 Emission results from increasing parking and toll fees

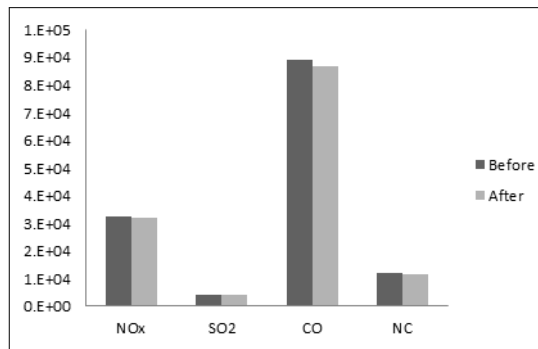
### 2. Introduction of low-carbon emitting vehicles

About 90% of the transportation sector worldwide is powered by fuels derived from oil. Regulating the dependence in oil consumption would also entail reduction in emission of air pollutants and GHGs. Different studies have presented that the plug-in hybrid vehicles improve fuel efficiencies by about 40-45% (L.Y. He and Y. Chen, 2013). Energy vehicles rate an average of 2.4-3.3times fuel efficiency than conventional vehicles (Thomas, 2009). In this study we assessed the effect of introducing electric powered vehicles in the road fleet. The researches assumed a 10% shift of fuel based cars to hybrid cars as shown in Table 4. The change in mode share was carried out in the assignment and simulated results show that CO emission dropped from 89,450g to 86,668g as shown in Fig. Switching to hybrid cars will entail an average decrease of 2.61% in emissions. The change is

relatively small because hybrid cars may not tailpipe emissions, greenhouse gas emissions and other pollutants may also be produced depending on the mix of the electricity used.

〈Table 4〉 Change in vehicle share by shifting to Hybrid cars

Shift 10% of cars to hybrid cars			
	Before	After	Total Change in share
Car	37.56	33.80	-3.76
Hybrid	0	3.76	3.76
Others	66.43	66.43	0



〈Fig. 8〉 Emission results from shifting 10% of cars to hybrid cars

## V. Conclusion

The rising economic growth has set forth an immense increase in road transport sector in Korea which consequently resulted to an increase in emissions of greenhouse gases and other air pollutants. Road traffic is the main contributor of CO<sub>2</sub> emissions in the local government. This was mainly because the road transportation was the most utilized mode choice for travel. In 2009, 89% of the total greenhouse gas emissions came from CO<sub>2</sub> due to the heavy dependence on fossil fuels of the road transportation. Precise inventories of emissions should be organized for the transportation sector in order to implement necessary policies fit for mitigation process to conform

to the goal of the government to reduce pollution. Since uncertainties were deemed to be existent in most emission estimates new methods for calculating greenhouse gases were considered.

Traffic models are one of the most utilized ways to generate traffic data. Macroscopic traffic models were made to simulate traffic data for large networks therefore making it possible to produce greenhouse gas estimations for local municipalities. This paper investigated and proposed that greenhouse gas calculation for the road transportation sector may be derived from a travel demand forecast using an innovative macroscopic traffic program VISUM. Since vehicle speed per link may be obtained, it is possible to improve computation of emission inventories for large road network. This study also noted that the accuracy of the emissions not only rely on the traffic data which was fed to the emission models but also to the accuracy of the inputs to the demand model. A careful review of the inputs should be implemented.

Discrepancies in the emission estimates were also observed in the TSA, HBEFA and Pollution-Emis. Such discrepancies may be attributable to the emission factors used for every model. The emission factors were not just constants in the emission estimates; rather they are important elements having considerable impacts. Most emission factors were rudimentary only considering the amount of pollutants per fuel consumptions. Although the emission factors of HBEFA are representative of the driving patterns of particular countries, our study still utilized HBEFA emission factors since they depict a wide variety of emission factors representing different traffic situations. The analysis of the causes of the emission discrepancies may not only account for the emission factors utilized in the models (TSA, Pollution-Emis, HBEFA) it is important to consider the effect of the implementation methodologies and boundaries related to the input data. The GHG emission estimate is affected by the pollutant, emission model type, emission factor curve, and change in distribution of

VMT and speed.

This study discussed the factors affecting the emission estimates. The overall accuracy of road traffic emissions requires an in-depth understanding of the methodologies used in the estimation process. Although we have presented that it was possible to obtain environmental impacts using a travel demand model, our research have shown limited literature about the validation of travel demand models, nevertheless, given the potential uncertainties introduced by conventional computation methods, it seems valuable to improve post-processing method and apply it in the development of emission inventories. This study recommends further validation efforts focused on creating models which is specific of the running fleet and more varied traffic conditions; furthermore country specific emission factors characterizing different traffic situations should be developed. The results of this study maybe generalized with further experiments especially on the reduction measures.

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저자소개



**Pennie Rose Anne R. Maurillo**  
2013년 3월 ~ 현재 : 공주대학교 교통공학과 석사과정  
2012년 2월 ~ 2013년 2월 : Vistaland, Mandaluyong, Philippines  
2006년 6월 ~ 2011년 3월 : University of Sto. Tomas, Manila, Philippines  
e-mail : pmaurillo@kongju.ac.kr  
연락처 : 010) 2191-5664



**정 현 지 (Jung, Hyeon-Ji)**  
2013년 3월 ~ 현재 : 국토연구원 국토인프라 연구본부 연구원  
2011년 3월 ~ 2013년 2월 : 공주대학교 석사(교통공학전공)  
2007년 3월 ~ 2011년 2월 : 공주대학교 학사(교통공학전공)  
e-mail : hjjung@krihs.re.kr  
연락처 : 010) 4068-5838



**이 선 하 (Lee, Seon-Ha)**  
2000년 3월 ~ 현재 : 공주대학교 건설환경공학부 도시·교통공학과 교수  
1999년 11월 ~ 2000년 2월 : LG-EDS ITS팀 팀장  
1998년 11월 ~ 1999년 11월 : 건설교통부 광역교통정책실 전문위원  
1991년 8월 ~ 1996년 10월 : 교통개발연구원 연구원(교통계획, 교통안전)  
1998년 11월 : 독일 칼스루헤 대학 박사(토목공학전공)  
1990년 8월 : 독일 베를린 공과대학 석사(토목공학전공)  
1986년 2월 : 고려대학교 학사졸업(토목공학전공)  
e-mail : seonha@kongju.ac.kr  
연락처 : 010) 3750-3049



**하 동 익 (Ha, Dong-Ik)**  
2011년 5월 ~ 현재 : 서울대학교 건설환경종합연구소 연구교수  
1992년 5월 ~ 1995년 8월 : 한국교통연구원  
1987년 8월 ~ 1992년 2월 : 미국 뉴욕 폴리테크닉대학교 교통공학과 박사  
1981년 3월 ~ 1983년 2월 : 홍익대학교 도시공학과 석사(교통공학전공)  
e-mail : dihha@naver.com  
연락처 : 010) 5023-1369