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QUANTIFICATION OF CARBON EMISSION REDUCTION BY U-TRANSPORTATION SERVICE EFFECT: A CASE STUDY OF DONGTAN U-CITY

Tae-Woong Jung, Mu-Wook Pyeon, and Jee-Hee Koo

Key words: U-City, U-transportation service, carbon emission, carbon reduction, greenhouse gases, estimation model, Dongtan U-City.

ABSTRACT

With the emergence of the response to climate change as a global agenda, UNFCCC member countries must report their Greenhouse Gas (GHG) emissions and absorptions. With conventional carbon emission estimation methods such as the IPCC Guideline, however, it is impossible to measure reduction of carbon emissions by U-City services. Therefore, this study proposed estimating carbon emission reductions by using U-transportation services as a model because this service appears to be the most effective among U-City services in terms of carbon emission reduction. This approach which is unique in Korea has also attempted to quantify the reduction of carbon emissions by a U-transportation service by applying it to Dongtan U-City. The average vehicle speed before U-transportation service was set to 29.62 km/hr based on reference data. The average vehicle speed after application of U-transportation service was estimated based on 22.6% of the average velocity growth rate which was obtained by applying ITS (Intelligent Transport System) to three cities (Daejeon, Jeonju, and Jeju). Because of increase in vehicle speed by U-transportation service, the carbon emissions in Dongtan U-transportation decreased by 10.7% from 591,678 tCO_2e/y to 528,527 tCO_2e/y. In terms of velocity growth rate by U-transportation service, the regression between carbon emissions (0% to 40% section) and velocity growth by U-transportation service was estimated.

I. INTRODUCTION

The government of South Korea enacted laws and increased R&D investments to ensure the success of the ubiquitous city (U-City) project. ‘U-City’ refers to a city where citizens are able to access ‘ubiquitous services’ anytime and anywhere through a modern infrastructure which is developed based on ubiquitous technology for the improvement of urban competitiveness and quality of life [13].

Responses to climate change led by advanced countries have spread to developing countries. Climate change has been one of the world’s most important matters because we have to reduce GHGs such as CO_2, a main cause of global warming. It has emerged as a major item on the agenda of international events [3, 7, 16, 20]. Examples include:

- the 1992 UNCED (United Nations Conference on Environment and Development) where the UNFCCC (United Nations Framework Convention on Climate Change) adopted the agenda of ESSD (Environmentally Sound and Sustainable Development),
- the 1997 UNFCCC at which Kyoto Protocol was adopted,
- the 15th Conference of the Parties (COP 15),
- the 2009 United Nations Climate Change Conference (so-called ‘Copenhagen Summit’),
- the G-8 Summit 2007 and
- the Davos Forum 2007 [8].

The increase of global attention to climate change means that industries, companies and individuals as well as countries must take the subject seriously and prepare appropriate responses to the issue [12, 18, 19, 22].

The Korean government set a goal to reduce GHG emissions by 30% BAU (Business as Usual) until 2020 as shown in Fig. 1. They established specific reduction plans for 471 companies. The government-led U-City project is also a part of the current efforts to reduce GHGs [2].

The UNFCCC member countries are expected to report anthropogenic emissions by human activity including activity data, sources, and greenhouse gas removals by sinks. The 2006 IPCC GL (Intergovernmental Panel on Climate Change Guideline) provides a methodology for estimating inventories of each country in these terms. However, there are limitations in its application to a U-City because U-City’s core factors (e.g., U-Infrastructure, U-Services, GHG emission sources,

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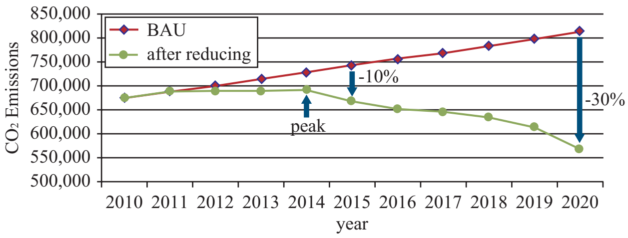

Fig. 1. Plan for greenhouse gas reduction by Korean government.

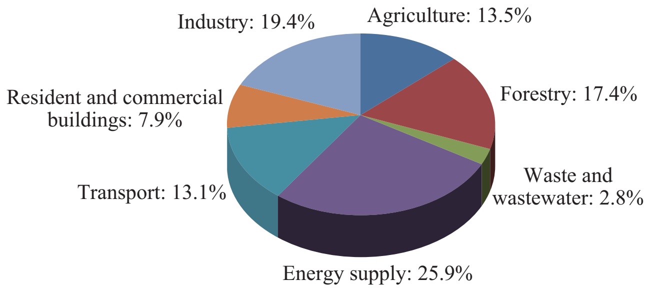

Fig. 2. Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-equivalent (Climate change 2007: Synthesis report p. 36 Fig. 2.1 reorganized).

emission factor, activity statistics, etc.) differs from conventional cities [17].

To address these problems, international standards groups such as ISO TC 207, ISO/IEC JTC 1, and ITU-T have performed a study to estimate carbon emissions from Information and Communications Technology (ICT) and develop its standard [6]. However, it is difficult to find an in-situ real study on the estimation of carbon emissions and carbon reductions in a U-City. A local authority which plans to develop U-City should develop the USP (Ubiquitous Strategy Plan) and the plan should include a U-Service plan. However, it is unknown what type of U-Service has the greatest impact on the carbon emission reduction in a U-City.

Therefore, this study aims to propose a method and model for estimating an input variable for assessing reduced amount of carbon emission due to U-transportation services using the equation between vehicle speed and carbon emissions provided by IPCC GL. This study attempted to quantify carbon emission reduction according to the application of U-transportation service by applying the model to Dongtan, the first and largest U-City in Korea.

II. U-TRANSPORTATION SERVICES, GHGS, AND INVENTORY

According to the Ubiquitous City Development Project Process Guidelines, U-Services are classified into 228 services in the following categories: public administration, public health, medical service, welfare, environment, security, disaster prevention, facility management, education, culture, tourism, sports, logistics, employment, and others. The U-transportation services, which include carbon emission-related realtime traffic control services and collect and manage traffic information (ex: traffic volume, vehicle speed, emergency situations, etc.) on a realtime basis. They are provided through various media such as VMS (Variable Message Sign) and automatically controlled traffic facilities. The U-transportation services optimize traffic flow by:

- increasing vehicle speed,
- preventing traffic congestion in intersections, and
- preventing car accidents by adjusting traffic light time and providing useful traffic information to drivers through mobile devices such as VMS or smartphone [24, 25].

IPCC identified six GHGs (CO_2, CH_4, N_2O, HFC_S, PFC_S, and SF_6) and classified GHG emissions and absorptions into five related sectors. However, it is too broad to target all GHGs and related sectors. Therefore, CO_2 was chosen for this study because it is the most dominant GHG, accounting for nearly 77% of total CO_2 equivalent GHG emissions in the world [17, 18, 21]. Among diverse sectors, road transportation (1A3b in IPCC GL) was in this study because it is highly correlated with U-transportation services. The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport, and industry, while residential and commercial buildings, forestry (including deforestation), and agriculture sectors have been growing at a lower rate. The sectoral sources of GHGs in 2004 are provided in Fig. 2 [1].

III. MODEL FOR ESTIMATING CARBON EMISSION REDUCTION BY U-TRANSPORTATION SERVICES

1. A Method for Estimating Carbon Emissions in Road Transportation

In the 2006 IPCC GL, tiers 1, 2, and 3 are used for estimating carbon emissions in road transportation. Korean local entities use 2006 IPCC GL tier 2 to estimate carbon emissions as shown in Eq. (1) [5, 17]:

$$Emission = \sum_{a} [\, fuel_a \times EF_a \,] \tag{1}$$

where
Emission: Emission in kg
fuel: Fuel consumed (TJ) (as represented by fuel sold)
EF: Emission factor (kg/TJ)
a: Fuel type (e.g., diesel, gasoline, natural gas, and LPG)

Fuel consumption for road transportation in local authorities, however, includes carbon emissions produced by vehicles from other local authorities. Therefore, if vehicle kilometer traveled (VKT) methodology is applied based on the vehicles operated in an area, the carbon emissions produced

Table 1. CO_2 emission factors by vehicle type (g/km).

representative vehicle category		emission factor functions
passenger car	passenger car	$y = 1555.4\ v^{-0.5766}$
	taxi	$y = 1539.4\ v^{-0.5748}$
van & bus	van	$y = 1671.3\ v^{-0.5453}$
	bus	$y = 4539.1\ v^{-0.4587}$
truck	truck	$y = 1671.4\ v^{-0.5433}$

by the vehicles which are not controlled by the local authority should be included. Also, national energy statistics do not classify fuel consumption data by vehicle type. Therefore, the VKT methodology proposed by NIER (National Institute of Environmental Research) has been applied and estimated as shown in Eq. (2) [15]:

$$Emission = \sum (Acitivity_{ab} \times EF_{ab}) \qquad (2)$$

where
Emission = Emission in kg
Activity = Vehicle kilometer traveled
EF = Emission factor (kg/TJ)
a = Type of vehicle
b = Velocity (km/h)

2. Application of the Model to Dongtan U-City

The relation between U-transportation services and carbon emissions can be considered in terms of the relationship between velocity growth and carbon emissions. In this case, emission factor functions describing the relationship between vehicle speed and carbon emissions are necessary. In Korea, EU CORINAIR (Core Inventories Air) and MOVES2010 (Motor Vehicle Emission Simulator 2010) by the USEPA (US Environmental Protection Agency) are available. This study used the emission factor equation of NIER, as shown in Table 1 [4, 14].

Air pollutant emission estimation methodology (II) published by the NIER identifies mean vehicle speed by city size. Otherwise, vehicle speed can be applied depending on city size as shown in Table 2. As shown in the table, Dongtan U-City is categorized as ‘Other Cities.’ Therefore, the vehicle speed before U-transportation services was set to 29.62 km/hr [15].

After the U-transportation services are applied, it would be ideal to measure an increase in vehicle speed. However, it requires considerable time and money. Furthermore, because a U-City is a relatively new concept, no previous statistical data are available. Lee and others (2004) performed on-spot investigations and analyzed the data from the detection system in Daejeon, Jeonju, and Jeju in order to find out changes in vehicle speed according to a business effect based on the ITS (Intelligent Transport System) which is similar to U-transportation service. As a result, increase in vehicle speed by 21.1%, 12.6% and 34.0% was observed for Daejeon, Jeonju, and Jeju, respectively. In this study, 36.31 km/hr, which was obtained by applying the average rate of vehicle speed growth from the three cities (22.6%), was selected as vehicle speed according to the application of the U-transportation services [10, 11].

Table 2. Application criteria and average vehicle speed by city size.

city size	application criteria and vehicle speed
metropolitan city	Seoul: 25.97 km/hr Busan: 25.00 km/hr Daegu: 28.10 km/hr Incheon: 23.70 km/hr Gwangju: 41.59 km/hr Daejeon: 28.20 km/hr Ulsan: 34.80 km/hr
other cities	National mean of vehicle speed on road section within top seven metropolitan cities of the nation **(29.62 km/hr)**
county	80% of speed limit by road

Table 3. No. of vehicles estimated in Dongtan U-City and average daily VKT.

Vehicle Type	No. of vehicles estimated in Dongtan U-City	average daily VKT (km)
passenger Car	99,821	38.1
taxi	1,917	168.0
van	11,054	40.3
bus	902	199.6
truck	25,829	47.6

The VKT can be estimated based on the following equation: average daily VKT (vehicle type) × no. of vehicles registered (vehicle type) × 365 days. The average daily VKT was estimated based on the 2009 Vehicle Mileage Report published by Korea Transportation Safety Authority, while the number of vehicles were estimated using statistical data from the Ministry of Land, Transport and Maritime Affairs. Both estimations are available by city, county, and district [9, 26].

The average daily kilometers traveled and the number of vehicles registered in Dongtan U-City were estimated based on the composition ratio of the statistical data of City of Hwaseong which is the neighboring city of Dongtan U-City. The results are shown in Table 3 [25].

Carbon emissions in road transportation in Dongtan U-City are estimated in Eq. (3):

$$Em = \frac{a \cdot v_i (1 + v_j)^b \times r_t \times d_t \times 365}{10^6} \qquad (3)$$

where
Em: Emissions in tCO_2e/year
a, *b*: Emission factor

Table 4. Comparison of carbon emissions before and after the application of U-transportation services in Dongtan.

Vehicle type	Carbon emissions (tCO_2e/year) A: Before U-transportation (at 29.62 km/hr)	Carbon emissions (tCO_2e/year) B: After U-transportation (at 36.31 km/hr)	Reduction rate: (A-B)/A × 100
passenger Car	325,715	289,610	11.1%
taxi	27,472	24,435	11.1%
van	45,579	40,786	10.5%
bus	67,114	61,125	8.9%
truck	125,799	112,570	10.5%
sum	591,678	528,527	10.7%

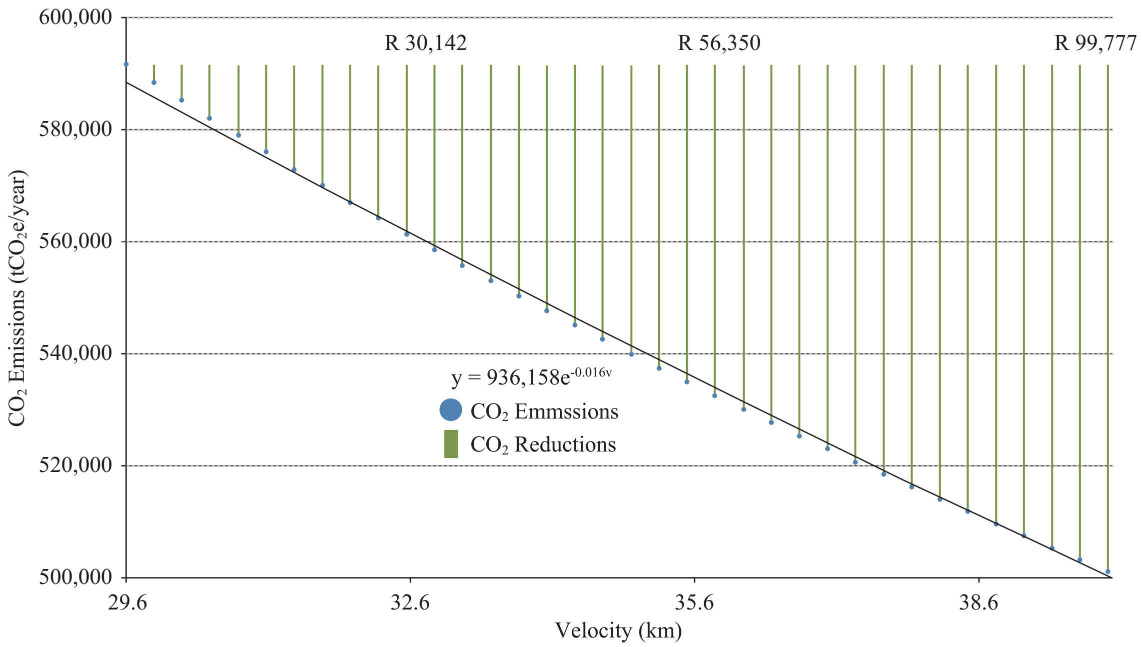

Fig. 3. Regression between carbon emissions and vehicle speed.

v_i: Vehicle speed before U-transportation service
v_j: Vehicle speed growth rate after U-transportation service
r: No. of vehicles estimated
d: Average daily vehicle kilometers traveled
t: Vehicle type

As vehicle speed increased by 22.6% from 29.62 km/hr to 36.31 km/hr according to the application of U-transportation services, carbon emissions in road transportation in Dongtan U-City decreased by 63,151 tCO_2e/y (10.7%) from 591,678 tCO_2e/y to 528,6527 tCO_2e/y in Table 4.

After setting vehicle speed as 29.62 km/hr for the status without the U-transportation service, a decrease in carbon emissions within the range of 0% to 40% of velocity growth rate according to the application of U-transportation service was estimated as shown in Fig. 3. A regression equation of $y = 936{,}158e^{-0.016v}$ was obtained for describing the relationship between vehicle speed and carbon emissions in Dongtan U-City. As vehicle speed increased up to the maximum level of 40%, carbon emissions decreased by 99,777 tCO_2e/y (17.0% in BAU).

IV. CONCLUSION AND REVIEW

Carbon emissions and reductions according to the application of U-transportation services have been estimated using emission factors between vehicle speed and carbon emissions that was derived from previous studies. The vehicle speed after implementing U-transportation services has been estimated as 36.31 km/hr. The estimation is based on 29.62 km/hr of the vehicle speed by NIER and 22.6% of average velocity growth rate from the reference data. In addition, regression between vehicle speed and carbon emissions was estimated.

Estimations of carbon emissions and carbon reductions after U-transportation services suggest the following: The estimation model developed in this study using reference data may be used for estimating decreases in carbon emissions after U-transportation services are implemented. Carbon emissions and reductions were quantified based on this model. This estimation model is also useful when actual data, which require considerable time and money to obtain, are not available.

In this study, the relations between U-transportation services and carbon emissions were considered in terms of increase in vehicle speed. Emission factors have been used to analyze the relationship between carbon emissions and vehicle speed. The effect of U-transportation services can vary depending on the scope of application on the road. However, this perspective has not been considered in this study.

Therefore, it may cause some uncertainties in the result of the study. Also, carbon emissions in U-transportation can be reduced by several factors including a decrease in traffic congestion and prevention of car accidents. If further study is performed on these effects of U-transportation services, it is expected that reduction of carbon emissions after the application of U-transportation services will be estimated more precisely. In addition, a local authority which plans U-Cities would be able to use this model in planning a ubiquitous strategy in order to establish USP with U-Services which have a great impact on carbon emission reduction.

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