EVALUATION OF TRANSPORT POLICY AND ENERGY DEMAND IN SEOUL METROPOLITAN REGION USING LEAP MODEL

By

Chanho Park

THESIS

Submitted to
School of Public Policy and Management, KDI
in partial fulfillment of the requirement
for the degree of

MASTER OF DEVELOPMENT POLICY

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Professor Jeong Ho Kim

Approval as of May 15, 2015

ABSTRACT

EVALUATION OF TRANSPORT POLICY AND ENERGY DEMAND IN SEOUL METROPOLITAN REGION USING LEAP MODEL

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In a view of sustainable development, growing demand for urban transport and its impact on the environment has large contributions on climate change and global warming.

This study simulates the impact of various urban pasenger transport policy options on energy consumption and CO2 emissions in Seoul metropolitan region. Identifying the carbon intensity of passenger transport mode in Seoul metropolitan region confirmed bus and metro emit 2.5 times and 55 times less CO2 than private car, respectively. Based on carbon intensity of each transport mode, congestion charge and bus rapid transit (BRT) policy were developed.

LEAP model was used to evaluate each policy scenario. Results of congestion charge policy show a relatively strong impact on reducing private car demand while bus, metro, and taxi demand were slightly increased. BRT policy shows a relatively strong imact on reducing taxi demand and bus absorbed most of demand shift from taxi. Congestion charge and BRT policies would complement by reducing total energy demand and CO_2 emissions from different sources.

ACKNOWLEDGEMENT

I first would like to express gratitude to my supervising professor Songu Choi and Dr. Jinyoung Park at the Korean Transport Institute for their valuable input and guidance throughout the project. Without their support and I would not be able to finish my research. I also would like to sincerely thank Dr. Sangjun Park at the Korean Transport Institute for sharing his knowledge on the LEAP model.

Dr. Tae Yong Jung, my lifelong mentor, I owe him a debt of gratitude for his guideance throughout the project, lecture, and counsel. Without him, I would never dreamed to conduct such research project.

Lastly and most importantly, I would like to thank to my family and my love Soohyun Yoo for their support and encouragement.

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1 INTRODUCTION

1.1 Background of Research

In urban areas, road transportation takes a large portion of energy consumption and energy related greenhouse gas (GHG) emissions. Specifically, public transport can mitigate large amounts of energy consumption and GHG emissions. Agglomeration of jobs, people, and services allow condensed development which makes public transport a more viable travel option. This study investigates carbon intensity of private vehicles and public transport to give rationale for sustainable transport policy. Furthermore, this study simulates the impact of various transport policy options on energy consumption and GHG emissions.

1.2 Scope and Methodology

As the expansion of urbanization weakens city boundaries and metropolitan transport becomes important, the geographical scope of this study is set to the Seoul metropolitan region, which is composed of Seoul, Incheon, and Gyeonggi province. The time span of the study runs to 2030 to check the long-term impact of transport policy on energy demand and GHG emissions. The object of study is limited to road passenger transport mode; including metro, bus, taxi, and private vehicle.

This study is composed of 4 stages of research to analyze current circumstances and find effective GHG mitigation policy options for sustainable urban transport.

The first stage is to analyze previous research and policies to draw limits and problems of current urban transport policy. This includes collecting raw data from the National Statistical Office, regional government, and research institute and process it to fit into research model.

The Second stage is to structure LEAP model based on the results of carbon intensity and project CO_2 emissions in the Business as Usual (BAU) scenario.

The third stage develops hypothetical transport policy scenarios based on practical data and analyzes each scenario via LEAP modelling.

Lastly, the study draws a rational urban transport policy based on the results of the study and suggests a sustainable pathway for Seoul metropolitan government.

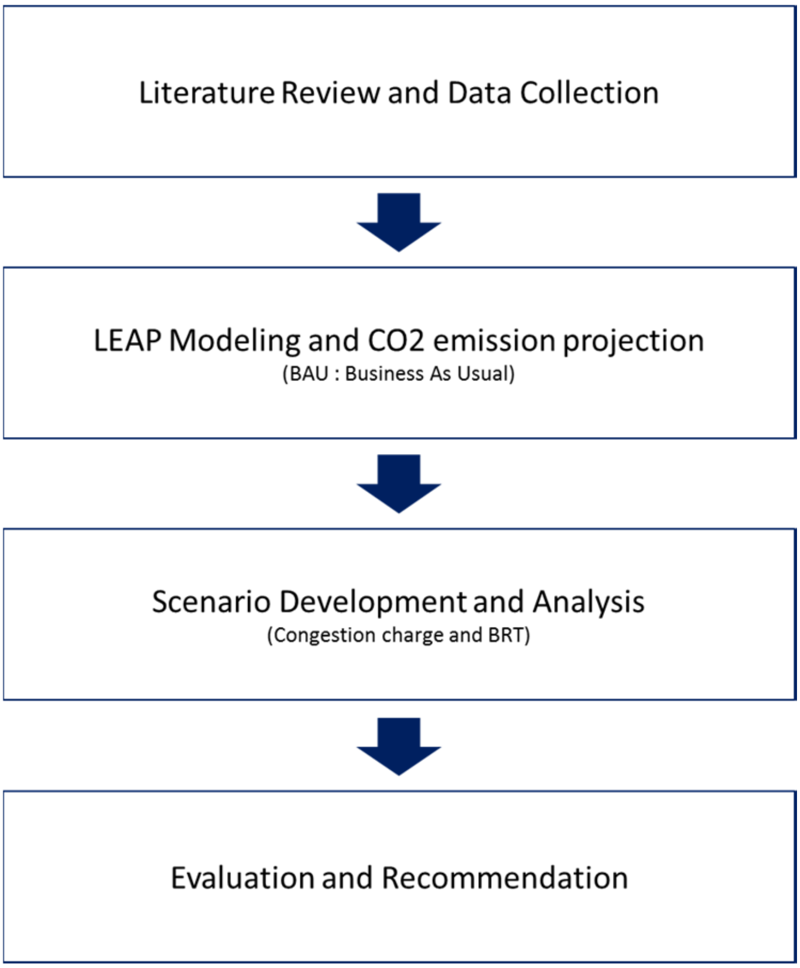

Figure 1 Research roadmap

2 LITERATURE REVIEW

2.1 Sustainable Development and Transport

2.1.1 Environment

The Transport sector has drawn more attention from global society as its impact on the environment (mostly climate change and GHGs emissions) and sustainable development become priority issues (Asian Development Bank 2012, International Energy Agency 2009). Many scholars (ChapmanLee 2007, MichaelisLaurie, DavidsonOgunlade 1996, TimilsinaGovinda, ShresthaAshish 2009) have pointed to the transport sector as a major source of energy consumption and GHGs emission; thus, it is a possible tool to mitigate climate change impacts. According to the International Energy Agency (IEA) report, in 2019, the transport sector will contribute 23 percent of energy-related carbon dioxide (CO_2) emissions and CO_2 emissions from the transport sector are projected to increase dramatically by the year 2030. Moreover, the IEA (2009) report points out that the transportation sector consumes approximately 19 percent of global energy and is expected to increase by the year 2013. With this regard, many countries and international organizations are looking to reduce GHGs from the transport sector.

2.1.2 Economy

Transport-related urban problems, such as traffic congestion and land use, are emerging in many countries. In World Bank's study (World Bank, 1994), cities GDP from time-sensitive industry have been negatively affected by traffic congestion from 3 to 6 percent and time losses of economic activities accounted at 2 percent (Europe) to 5 percent (Asia). In many developed and emerging countries, the portion of paved road causes conflict in land use as it takes from 35 percent of land in automobile-oriented cities (e.g., Houston, Atlanta) to 20 percent (e.g., Seoul, São Paulo) (VasconcellosEduardo, 2001)

2.1.3 Society

Transport is considered a basic social service along with water supply, sanitation, affordable housing and education for urban residents. According to Sung's (2010) study, accessibility to affordable and appropriate transport (i.e. subway, bus station) in a region can positively influence physical health and quality of life of residents in that region. Also, in the context of social integration (including social inclusion and social cohesion), transport plays a critical role to minimizing regional, physical, economical exclusion and social conflict (MoChanghwan, HwangSanggyu, GwonYungjong, 2010). Lastly, socially marginalized groups can be easily excluded from appropriate economic activities due to lack of affordable transport mode.

2.2 Urbanization and Urban Transport

The scale and pace of urbanization in the world continues at an unprecedented rate. As of 2010, the world population in urban areas already reached 50 percent. If current trends hold, it is expected to reach 70 percent by 2050 (UN DESA, 2009). While urbanization fertilizes economic prosperity in city areas, the demand for urban transport keeps increasing to fulfill the needs from growing population and economic activities. At a global level, approximately

8 billion trips are made daily in cities and nearly 47 percent of those trips are made by private vehicles (Pourbaix, 2012) which mostly cause urban traffic congestion.

Significant empirical research findings (SchillerPreston, BruunEric, KenworthyJeffrey, 2010) emphasize some key elements of sustainable passenger transport below;

- *Meet basic access and mobility needs in ways that do not degrade the environment*
- *Not deplete the resource base upon which it is dependent*
- *Serve multiple economic and environmental goals*
- *Maximize efficiency in overall resource utilization*
- *Improve or maintain access to employment, goods and services while shortening trip lengths and/or reducing the need to travel*
- *Enhance the livability and human qualities of urban regions*

2.3 Development of Transport System in Seoul Metropolitan Region

The first public transport launched in Korea was the tram system in 1899. The tram was a model project in conjunction with the electricity network developed in Seoul. After having endured the chaos of Korean contmporary history, the tram stopped its operation in 1968 and the bus transportation had become the major public mode until the first metro opened in 1974.

As the economic development plan started in 1967 and the influx of labors congested in Seoul, the bus services could not meet the demand in a stable and pleasant manner. Therefore, the city expanded transport infrastructure in 1974 by openning the first metro system to meet the overflow of public transport demand. While the metro system had gradually extended their service areas, the buses had lost ridership due to unstable and lack of puctuality. Also, as the economic growth affirmed the consumer confidence, private ownership for passenger car accelerated in the mid-1980. Once the ownership reached one million in 1988, the numbers showed exponential growth for a decade until the economy being hit by the financial crisis in 1997. As a result, the increased private passenger car ownership affected traffic congestion, car accidents, and reduction on bus ridership.

Furthermore, as the economy and population grew, the urban sprawl started to happen forming metropolitan area by developing new cities in the periphery of Seoul territory. One of the result of urban sprwarl in transportation sector was increased demand for inter-city transport. Related city municipalities competed with each other to provide public transport and the administrative boundaries become a constraint in delivering convenient intercity transport. Therefore, the need for a new institution that would coordinate regional transportation plan had grown. Following the reforme of Seoul public transportation in 2004, the Metropolitan Transportation Authority was founded to coordinate discussion of inter-city transportation plan in Seoul Metropolitan region (Hwang 2012).

3 POLICY EVALUATION MODEL

3.1 Energy and Environment Evaluation Model

3.1.1 MARKAL Model

MARKAL (Market Allocation) Linear Programming model was developed by the IEA (International Energy Agency) from 1976 to 1979 and has been used by over 100 institutes globally. The purpose of MARKAL was to analyze energy systems, but with several upgrades, it is used for material modeling, including the material life cycle. When technology and cost information of future technology are available, competitiveness and effectiveness of future technology can be tested through the MARKAL model (Internation Energy Agency 2010).

Governments, international institutes (IEA, OECD, and IPCC), and other energy related research and development institutes are using the MARKAL model to evaluate environmental strategy, energy policy, industrial policy, and policy instruments.

Lately, the TIMES (The Integrated MARKAL-EFOM System) model is expanding its coverage. The TIMES model is a combination of the MARKAL model and the EFOM (Energy Flow Optimization Model) and it offers a technological foundation to project long-term energy dynamics (Internation Energy Agency 2010).

Table 1 MARKAL Model Information

Category	Content
Purposes	- Energy Strategy Development - Energy Suppply under Conditions - Target-based Energy Analysis
Assumptions	Low degree of endogenization / Focused on Energy Sector
Type	Bottom-Up
Methodology	Tool Box / Optimization
Level	Local and National / only Energy Sector
Time Horizon	Medium and Long term
Data requirements	Quantitative and Monetary / Disaggregated

Source: (Van BeeckN. 1999), “Classification of Models”

3.1.2 MESSAGE Model

The MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) model is developed by IIASA (International Institute for Applied Systems Analysis) to optimize energy systems at the national level. The MESSAGE model evaluates alternative energy supply strategies which comply with user constraints such as limits of investment, amount of resources, trade, and environmental regulations (International Institute for Applied Systems Analysis 2013).

Table 2 MESSAGE Model Information

Category	Content
Purposes	- Energy Strategy Development - End-user Analysis
Assumptions	Detailed description of End-user and Renewable Energy
Type	Bottom-Up
Methodology	Optimization
Level	Local and National / only Energy Sector
Time Horizon	Medium and Long term
Data requirements	Quantitative and Monetary / Disaggregated

Source: (Van BeeckN. 1999), “Classification of Models”

3.2 LEAP Model

3.2.1 Introduction

The LEAP (Long-range Energy Alternative Planning) model was created in 1980 by SEIB (Stockholm Environmental Institute Boston) to provide a flexible tool for long-range integrated energy planning (SEI 2014).

LEAP has been adopted by thousands of organizations in more than 190 countries worldwide including government agencies, research institutes, academics, and industries. LEAP can be used for resource planning, greenhouse gas (GHG) mitigation assessments, and Low Emission Development Strategy (LEDS). Also, many countries use LEAP to report to the U.N. Framework Convention on Climate Change (UNFCCC) as a part of their commitment (SEI 2014).

LEAP is an integrated modeling tool which can be used to track energy consumption, production and resource extraction in all economic sectors. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. LEAP can also be used to analyze emissions of local and regional air pollutants, making it well-suited to studies of the climate and of local air pollution reduction (SEI 2014). LEAP is flexible enough for users with a wide range of expertise from experts to junior researchers.

Table 3 LEAP Model Information

Category	Content
Purposes	- General: Exploring, forecasting - Specific: Demand, supply, environmental impacts, integrated approach (energy policy, environmental policy, biomass- and land-use assessment, etc.)
Assumptions	- Demand: high degree of endogenization and description of all sectors in economy - Supply: simple description of end-uses and supply technologies, including some renewable
Type	Demand: top-down / Supply: bottom-up
Methodology	Demand: econometric or macro-economic / Supply: simulation
Level	Local, national, regional, global
Sectoral Coverage	All sectors
Time Horizon	Medium, long term
Data requirements	Quantitative, monetary, aggregated / disaggregated

Source: (Van BeeckN. 1999), "Classification of Models"

3.2.2 LEAP Model Structure

LEAP is not a model of a particular energy system (SEI 2014), but rather a tool that can be used to create models of different energy systems with its own data structures. LEAP supports a wide range of different modeling methodologies. On the demand side these range from bottom-up, end-use accounting techniques to top-down macroeconomic modeling. LEAP also includes a range of optional specialized methodologies such as stock-turnover modeling for areas such as transport planning. On the supply side, LEAP provides a range of accounting and simulation methodologies that are powerful enough for modeling electric power generation and capacity expansion planning. Also methodologies are flexible and transparent to allow LEAP to easily incorporate data and results from other models.

LEAP’s modeling capabilities operate at two basic conceptual levels. At the first level, LEAP's built-in calculations handle all of the "non-controversial" energy, emissions and cost-benefit accounting calculations. At the second level, users enter spreadsheet-like expressions that can be used to specify time-varying data or to create a wide variety of sophisticated multi-variable models, thus enabling econometric and simulation approaches to be embedded within LEAP’s overall accounting framework. The latest version of LEAP (version 2014.0.1.14) also supports optimization modeling which allows the construction of least cost models of electric system capacity expansion and dispatch, potentially under various constraints such as limits of CO_2 or local air pollution (SEI 2014).

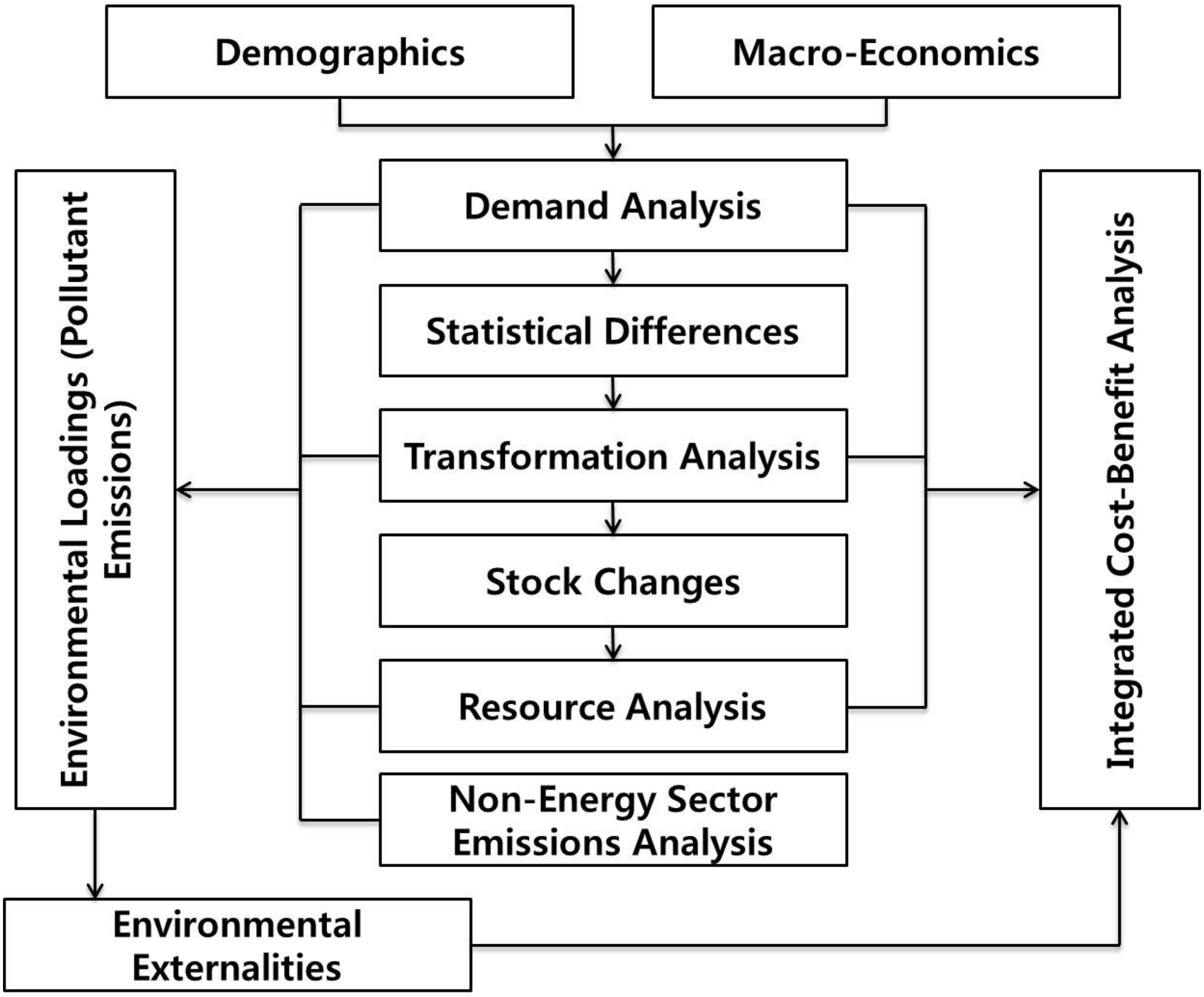

Figure 2 LEAP model Structure

Source: **(SEI 2014)**

4 RESEARCH QUESTIONS AND MODEL DEVELOPMENT

4.1 Research Questions and Hypothesis

RQ 1	**Demand Policy**	Increase and expand congestion fee will decrease energy demand of passenger transport.	**H0**	Increase and expansion of congestion fee will not affect energy demand of passenger transport.
			H1	Increase and expansion of congestion fee will decrease energy demand of passenger transport.
RQ 2	**Supply Policy**	Increase public transport supply will decrease energy demand of passenger transport.	**H0**	Increase public transport supply will not decrease energy demand of passenger transport.
			H1	Increase public transport supply will decrease energy demand of passenger transport.

RQ 1 based on demand control policy scenario of increase and expand congestion fee. Currently Seoul metropolitan government charges a congestion fee at Namsan tunnel 1 and 3 for 2,000 KRW. Increasing and expanding the congestion fee will decrease energy demand of passenger transport by reducing private car use. Consequently, CO_2 emission from transport sector will decrease.

RQ 2 based on supply control policy scenario of increasing public transport service volume in peak hours. Private vehicle demand comes from mostly commuting and business purpose (ParkSangjoon, KimHeekyung, JooJinho 2012). Among the two main causes, commuting is feasible to control by increasing public transport service volume.

4.2 Basic Assumption and Data

Assumption	**Subject**
Base year	2010
Period of Analysis	2015 ~ 2030
Target year	2015, 2020, 2025, 2030
Default unit	Energy Unit: TOE (Ton of Oil Equivalent) Monetary Unit: USD (constant 2010) Distance Unit: Kilometer Environmental Loading: Energy based kg/ BTU Transport Based: gram/passenger-km
Level 1 Demand Category	Public Transport Private Transport
Level 2 Demand Category	Public – Bus/Metro/Taxi Private – Passenger car
Fuel type	Gasoline/Diesel/LPG/CNG/Electricity

$$\textit{Energy Use} = \textit{Stock of Vehicles} \times \textit{Annual Vehicle Mileage} \times \textit{Fuel Economy}$$

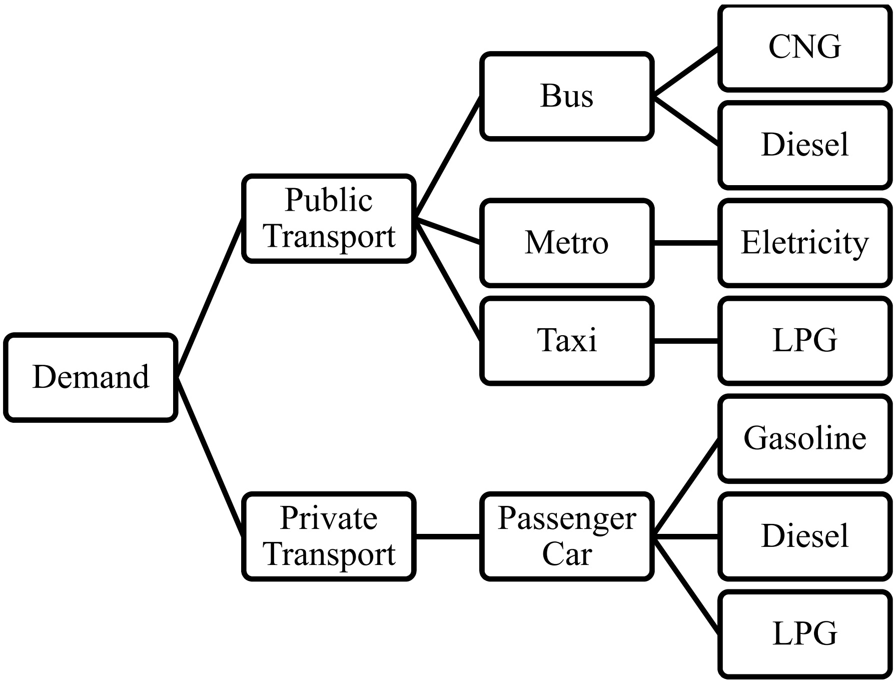

Figure 3 Energy Demand Data tree

Transport demand data are organized as shown in Figure 4. To check mode share change by policy scenario, demand is divided into public transport and private transport. Public transport is divided into Bus, Metro and Taxi to see the change of each transport mode by policy scenario. Finally, each transport mode is divided into fuel type as each fuel has a different emission factor.

4.3 Computation of carbon intensity in Seoul Metropolitan Region

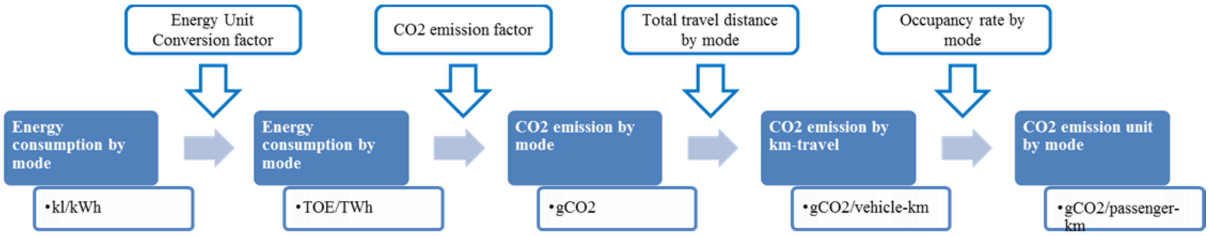

Figure 4 Flow chart of carbon intensity computation

Source: Re-developed by author based on (J. Ko, W. Kim, et al. 2009)

Carbon intensity can be computed by dividing CO_2 emissions of mode by total travel distance of mode.

Energy consumption (gasoline, diesel and LPG) data for private passenger vehicle and taxi extracted from ‘Energy Census’ by the Korea Energy Economics Institute (KEEI). CNG consumption data for bus extracted from ‘Yearbook of Regional Energy Statistics’ by KEEI and diesel consumption data for bus was not available from any statistics data, so this study uses total number of registered public buses from the Korean Statistical Information Service (KOSIS) and applied the diesel-CNG bus ratio from the Ministry of Environment (MoE) to extract diesel consumption by public buses. Oil conversion factor from the Korea Energy Management Corporation (Korea Energy Management Corporation 2014) was used to convert different types of fuel to a TOE base and CO_2 emissions factors from the IPCC guideline (GragAmit, KazunariKainou, PullesTinus 2006) was used to convert energy consumption to CO_2 emissions by mode and by fuel type.

Table 4 Ton of Oil equivalent Values by Energy Source

Type	Energy Source	Unit	Gross Caloric Value			Net Caloric Value		
			MJ	kcal	TOE	MJ	kcal	TOE
Oil	Crude Oil	kg	44.9	10,730	1.073	42.2	10,080	1.008
	Gasoline	ℓ	32.6	7,780	0.778	30.3	7,230	0.723
	Kerosene	ℓ	36.8	8,790	0.879	34.3	8,200	0.820
	Diesel	ℓ	37.7	9,010	0.901	35.3	8,420	0.842
	Bunker-A oil	ℓ	38.9	9,290	0.929	36.4	8,700	0.870
	Bunker-B oil	ℓ	40.5	9,670	0.967	38.0	9,080	0.908
	Bunker-C oil	ℓ	41.6	9,950	0.995	39.2	9,360	0.936
	Propane	kg	50.4	12,050	1.205	46.3	11,050	1.105
	Butane	kg	49.6	11,850	1.185	45.6	10,900	1.090
	Naphtha	ℓ	32.3	7,710	0.771	30.0	7,160	0.716
	Solvent	ℓ	33.3	7,950	0.795	31.0	7,410	0.741
	Jet Kerosene	ℓ	36.5	8,730	0.873	34.1	8,140	0.814
	Asphalt	kg	41.5	9,910	0.991	39.2	9,360	0.936
	Lubricant	ℓ	39.8	9,500	0.950	37.0	8,830	0.883
	Petroleum Coke	kg	33.5	8,000	0.800	31.6	7,550	0.755
	Heavy ends 1	ℓ	36.9	8,800	0.880	34.3	8,200	0.820
	Heavy ends 2	ℓ	40.0	9,550	0.955	37.9	9,050	0.905
Gas	Liquified Natural Gas	kg	54.6	13,040	1.304	49.3	11,780	1.178
	Town Gas(LNG)	Nm3	43.6	10,430	1.043	39.4	9,420	0.942
	Town Gas(LPG)	Nm3	62.8	15,000	1.500	57.7	13,780	1.378
Coal	Domestic Anthracite	kg	18.9	4,500	0.450	18.6	4,450	0.445
	Foreign Anthracite Fuel	kg	21.0	5,020	0.502	20.6	4,920	0.492
	Foreign Anthracite Coal	kg	24.7	5,900	0.590	24.4	5,820	0.582
	Other Bituminous	kg	25.8	6,160	0.616	24.7	5,890	0.589
	Bituminous Coal	kg	29.3	7,000	0.700	28.2	6,740	0.674
	Sub-bituminous Coal	kg	22.7	5,420	0.542	21.4	5,100	0.510
	Coke	kg	29.1	6,960	0.696	28.9	6,900	0.690
Electricity & etc.	Electricity (Generation)	kWh	8.8	2,110	0.211	8.8	2,110	0.211
	Electricity (Consumption)	kWh	9.6	2,300	0.230	9.6	2,300	0.230
	Firewood	kg	18.8	4,500	0.450	-	-	-

Source: (Korea Energy Management Corporation 2014) Oil Conversion Tons Calculated

Table 5 Carbon Emission Factors by Fuel Type

Fuel Type				Carbon Emission Factor	
				Kg C/GJ	Ton C/TOE
Liquid Fossil Fuel	Primary	Crude Oil		20.00	0.829
		Liquified Patroleum Gases		17.20	0.630
	Secondary	Gasoline		18.90	0.783
		Aviation Gasoline		18.90	0.783
		Kerosene		19.60	0.812
		Jet Kerosene		19.50	0.808
		Diesel		20.20	0.837
		Heavy Gas Oil		21.10	0.875
		LPG		17.20	0.713
		Naphtha		20.00	0.829
		Bitumen		22.00	0.912
		Lubricants		20.00	0.829
		Petroleum Coke		27.50	1.140
		Refinery Feedstock		20.00	0.829
Solid Fossil Fuel	Primary	Anthracite		26.80	1.100
		Bituminous	Coal Coke	25.80	1.059
			Other Bituminous	25.80	1.059
		Lignite Coal		27.60	1.132
		Peat		28.90	1.186
	Secondary	BKB & Patent Fuel		25.80	1.059
		Coke		29.50	1.210
Gaseous Fossil Fuel		Liquified Natural Gas		15.30	0.637
Biomass		Solid Biomass		29.90	1.252
		Liquified Biomass		20.00	0.837
		Gaseous Biomass		30.60	1.281

Source: (GragAmit, KazunariKainou, PullesTinus 2006) Carbon Emission Factors

$$CO_2 \text{ emission} = \sum_j [Fuel_j * \left(\frac{EI}{Fuel}\right)_j * \left(\frac{CO_2\ emission}{EI}\right)_j]$$

CO_2 emission: CO_2 emission

Fuel: Fuel consumption

EI: Energy intensity

j: Fuel type (Gasoline, Diesel, LPG, CNG and Electricity)

To compute CO_2 emissions per vehicle-km of travel, CO_2 emissions by mode and by fuel type are divided by total traveled distance of each transport mode and fuel. Total traveled distance data were collected from the Korea Transportation Safety Authority (Korea Transportation Safety Authority 2011).

The Metro consumes electricity not fossil fuel and it does not emit CO_2 for its operation. However, electricity is generated from fossil fuel and this study uses power generation emission factors from the Korea Power Exchange (KPX) to compute CO_2 emissions from electricity use. Electricity consumption data and total traveled distance of metro were collected from the 'Yearbook of Regional Energy Statistics' by KEEI.

To compute CO_2 emissions per passenger-km of travel, CO_2 emissions per vehicle-km of travel is divided by average occupancy rate[1] which was collected from the 'Yearbook of National Transport Statistics' by The Korea Transport Institute (KOTI). However, average occupancy rates for the metro is not available from KOTI's database. In order to collect average occupancy rate for the metro, this study uses the number of metro operation, the number of metro passengers per day and average rolling stocks per train.

[1] How many people in a vehicle for a single trip.

$$\text{Average passenger occupancy rate} = \frac{\text{Number of passenger per day}}{\text{Number of operation per day*average rolling stocks per train}}$$

This study focuses on Greenhouse Gas (GHG) emissions from road transportation specifically on passenger travel. In this regard, carbon intensity for aviation and marine transport are not being considered. For the same reason, carbon intensity for road freight has not been considered.

In general, GHGs means CO_2, CH_4, N_2O, HFCs, PFCs, SF_6. However, this study concerns itself only with CO_2 emissions rather than all GHGs to simplify the research and because GHG emissions from road transport is mainly caused by CO_2.

4.4 Results of carbon intensity in Seoul Metropolitan Region

Carbon intensity of Seoul metropolitan region in 2011 is shown as <Figure 4>. In the case of CO_2 emissions per vehicle-km of travel, private passenger cars in all fuel types show lower carbon intensity than public transport (Taxi, Bus and Metro). However, in the case of CO_2 emissions per passenger-km of travel, public transport (except Taxi) shows much lower carbon intensity than private passenger cars. This result is mainly due to occupancy rates of public transport (Bus and Metro) that are much higher than private passenger cars.

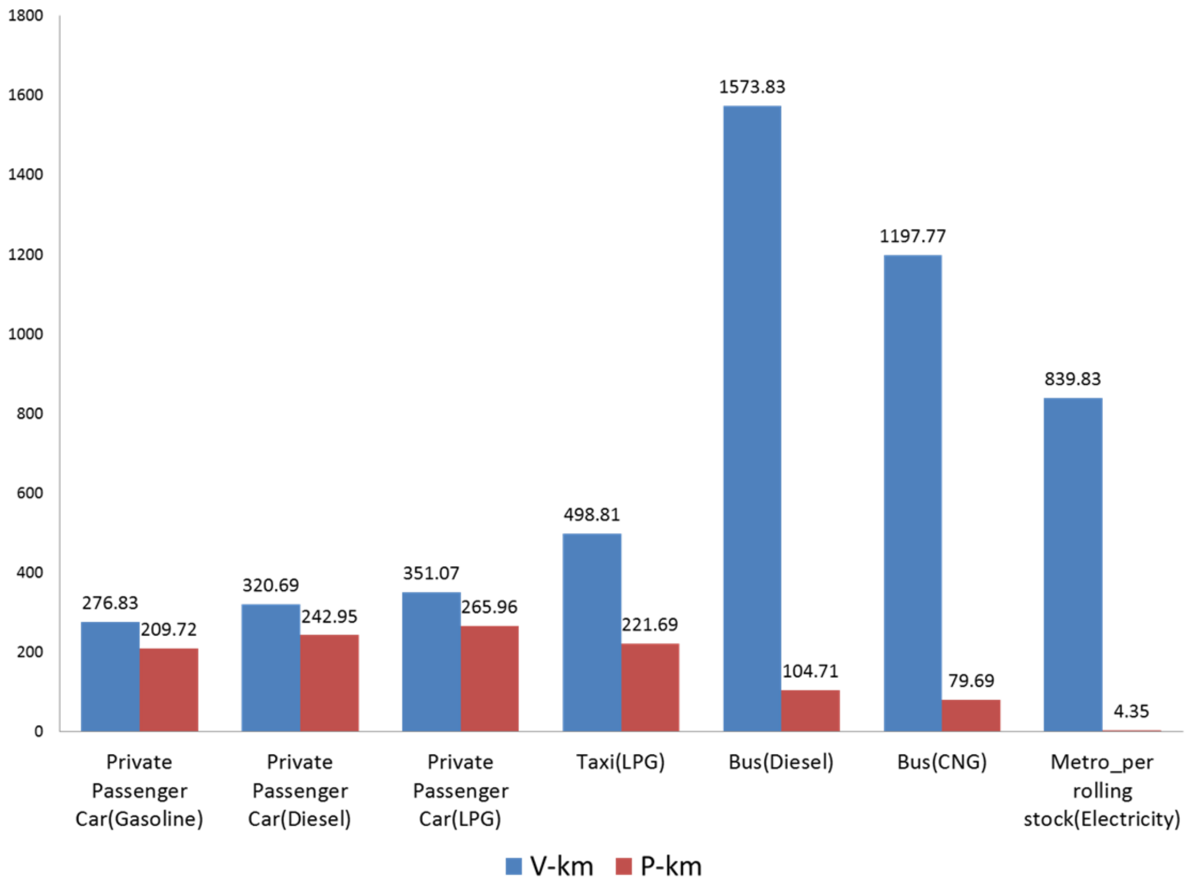

Figure 5 Carbon intensity by transport mode in Seoul Metropolitan Region (2011)

Unit: vehicle-km and passenger-km

The results of carbon intensity of each travel mode shows clear basis for the needs of transport demand control and public transport promotion policy. Average carbon intensity (passenger-km) of a private passenger car (239.54g/p-km) is 2.6 times higher than the average carbon intensity of a bus (92.2g/p-km), moreover 55 times higher than the carbon intensity of metro.

5 ANALYSIS

5.1 Scenario development

A congestion charge is suggested as one of the most effective transport demand control policies in many studies (Asian Development Bank 2012) (ChapmanLee 2007) (ChoiJinseok, 외. 2011) (KoJoonho, KimSoonkwan, Traffic Management Strategies in Seoul: Value Pricing Approaches 2007) (SantosGeorgina, BehrendtHannah, TeytelboymAlexander, Part II: Policy instruments for sustainable road transport 2010). Even if public acceptance of a congestion charge policy is still doubtable, its effect is clear. For example, London introduced its congestion charge policy in February 2003 and with a few years of adjustment in payment system and price, automobile traffic declined about 20% (approximately 20,000 vehicles per day), resulting in a 10% automobile mode share (LitmanTodd 2011). Stockholm also introduced its congestion charge policy in 2006 as a trial and continued after. In the case of Stockholm, traffic declined about 22% (approximately 100,000 passages per day) (City of Stockholm 2006).

Seoul has its own congestion charge scheme in Namsan tunnel 1 and 3 since 1996. However, after 10 years of its operation, traffic volume has recovered and keeps increasing with the same price in effect for 18 years. Many studies (KoJoonho, KimSoonkwan, Traffic Management Strategies in Seoul: Value Pricing Approaches 2007)(LeeJoo Bong, ParkHyunshin, KimDongkyu 2012)(Seoul Institute, 2001[2], KOTI, 2004[3], KRIHS, 2006[4]) on

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[2] 서울시정개발연구원 (2001) 서울시 혼잡통행료 징수체계보완연구

[3] 한국교통연구원 (2004) 혼잡통행료 제도 확대시행의 효과분석

congestion charge of Seoul Metropolitan region have suggested increasing its price and expanding the charging area, but no policy has been applied yet.

In a view of public transport supply policy, a Bus Rapid Transit (BRT) option has been considered and implemented in many countries (MoChanghwan, KwonYoungjong, A Basic Study on the Operating System of Bus Rapid Transit(BRT) 2007) (CerveroRobert 2013) (CreutzigFelix, HeDongquan 2009) to increase public bus ridership. Dedicated bus lane increases average bus speed and isolated platforms provide a safer place for passengers, which makes bus service more attractive.

5.1.1 Scenario 1: Business as usual (BAU)

For the business as usual scenario, year 2012 was selected as the base year and this scenario was designated as the base scenario. This scenario was based on a continuation of recent trends. By extrapolating these trends, values were projected to 2030 without any change.

5.1.2 Scenario 2: Transport Demand Control (Congestion charge)

Seoul Institute (KoJoonho, KimSoonkwan, Traffic Management Strategies in Seoul: Value Pricing Approaches 2007) applied a congestion charge of 2,000 Korean Won (KRW), 4,000 KRW, and 6,000 KRW in the Central Business District (Gangnam and Jongno) and analyzed its impact on transport mode share change in Seoul.

Table 2 shows transport mode share change in Seoul followed by different congestion charges. In this scenario, the mode share change of each transport mode by each congestion

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[4] 국토연구원 (2006) 효율적인 교통혼잡통행료 정책의 도입방안 연구

charge level was applied to the LEAP model to project the impact of congestion charges on energy demand and CO_2 emissions in the road-passenger transport sector.

Table 6 Impact of Congestion Charge on Transport Mode Share in Seoul

Unit: percent

	Transport Mode	w/o Congestion Charge	with Congestion Charge (Gangnam and Jongno)		
		Mode Share (A)	Mode Share (B)	Change (C) (B-A)	% of Change (C/A)
KRW 2,000	Private Vehicle	23.39	23.13	- 0.26	- 1.1
	Taxi	8.10	8.19	+ 0.03	+ 0.3
	Bus	32.19	32.24	+ 0.05	+ 0.2
	Metro	36.32	26.50	+ 0.18	+ 0.5
KRW 4,000	Private Vehicle	23.39	22.83	- 0.56	- 2.4
	Taxi	8.10	8.16	+ 0.06	+ 0.7
	Bus	32.19	32.35	+ 0.16	+ 0.5
	Metro	36.32	36.65	+ 0.33	+ 0.9
KRW 6,000	Private Vehicle	23.39	22.60	- 0.79	- 3.4
	Taxi	8.10	8.19	+ 0.09	+ 1.1
	Bus	32.19	32.45	+ 0.26	+ 0.8
	Metro	36.32	36.77	+ 0.45	+ 1.2

Source: (KoJoonho, KimSoonkwan, Traffic Management Strategies in Seoul: Value Pricing Approaches 2007)

5.1.2.1 Scenario 2A: Congestion charge KRW 2,000

When a congestion charge of KRW 2,000 is applied to the CBD in Seoul, the mode share of private vehicles is expected to decline 1.1% and the mode shares of taxi, bus, and metro are expected to increase 0.3%, 0.2%, and 0.5% respectively.

5.1.2.2 Scenario 2B: Congestion charge KRW 4,000

When a congestion charge of KRW 4,000 is applied to the CBD in Seoul, the mode share of private vehicles is expected to decline 2.4% and the mode shares of taxi, bus, and metro are expected to increase 0.7%, 0.5%, and 0.9% respectively.

5.1.2.3 Scenario 2C: Congestion charge KRW 6,000

When a congestion charge of KRW 6,000 is applied to the CBD in Seoul, the mode share of private vehicles is expected to decline 3.4% and the mode shares of taxi, bus, and metro are expected to increase 1.1%, 0.8%, and 1.2% respectively.

5.1.3 Scenario 3: Public Transport Promotion (Expand BRT lane)

Bus Rapid Transit (BRT) is a practical solution for a metropolitan government which has limited budget and geographical difficulties to implement a metro system. BRT systems require only a tenth of metro system construction costs for an equal effect and it can be installed on soft ground and near national heritage sites[5].

According to an Asia Development Bank (ADB) report (WrightLloyd, KimNawon, PaulaJoanna, Technical Assistance for Sustainable Fuel Partnership Study: Exploring an Innovative Market Scheme to Advance Sustainable Transport and Fuel Security_2nd Mid-Term Report 2011), expanding BRT routes can increase ridership by absorbing private vehicle demand. The report projects impact of BRT expansion scenarios in Ahmedabad, Bangkok, Davao, Lanzhou, and Vientiane and results are varied from 22 percent to 1 percent

[5] National heritage site is not viable for a metro system due to tremor occurred by train operation.

passenger kilometer changes. Ahmedabad shows the most similarities with Seoul in population density, city structure and transport mode share proportion compared to other cities. For these reasons, this research chose the Ahmedabad case as an example to apply the BRT scenario in the Seoul metropolitan region. To reduce application error, numbers in moderate scenario are used.

The ADB report assumed BRT promotion will cause an increase of 5% to 12% in BRT passenger kilometers from 2015 to 2020 and the additional demand comes from light duty vehicles (LDV) (5%), Two-wheeler (50%), Three-wheeler (15%), and Conventional Bus (30%). Figure 5 shows BRT demand change and its origin in Ahmedabad.

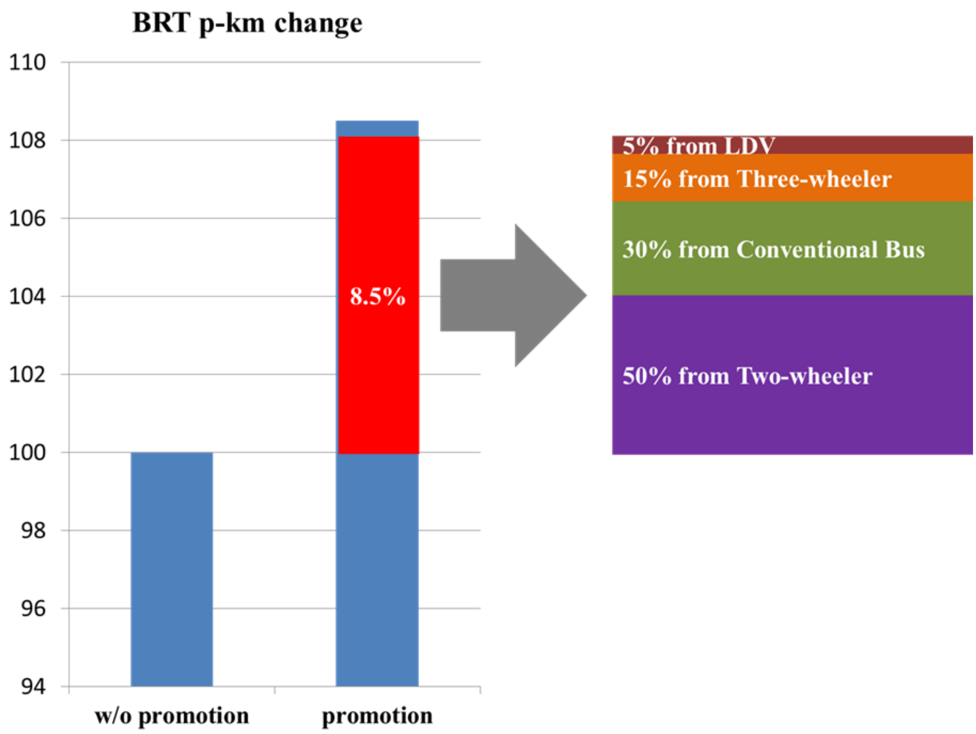

Figure 6 BRT demand change and its origin

Source: Re-developed by author based on ADB report (WrightLloyd, KimNawon, PaulaJoanna, Technical Assistance for Sustainable Fuel Partnership Study: Exploring an Innovative Market Scheme to Advance Sustainable Transport and Fuel Security_2nd Mid-Term Report 2011)

In this research, numbers are adjusted to fit the Seoul metropolitan transport structure. The range of BRT demand change (5% to 12%) is simplified to the median (8.5%). The demand shift from two-wheeler and conventional bus are ignored since passenger travel demand from two-wheeler in Seoul is marginal and the demand of BRT and conventional bus are integrated in this research. LDV is assumed as private vehicle and Three-wheeler is assumed as taxi in this research and its demand shift percentage are adjusted to Seoul data. In summary, the BRT demand change was a 1.7% increase and private vehicle and taxi demand decreased by 0.12% and 2.6% respectively.

5.2 LEAP Analysis Process

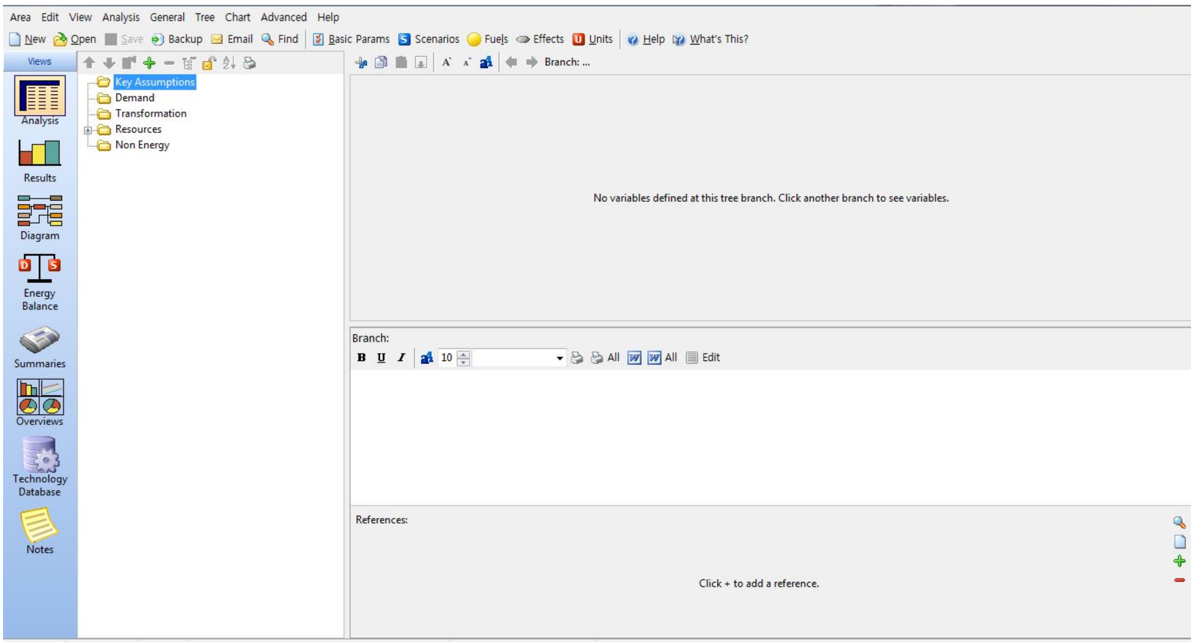

Figure 7 LEAP model Initial Page

The LEAP model has several view menus on the left side bar, the Analysis, Results, Diagram, Energy Balance, Summary, Overview, Technology Database, and Notes as figure 7 shows. The Anaysis view is the place where the user creates their own data structures, models and assumptions in LEAP and the Results view displays results in detail for all parts of the model.

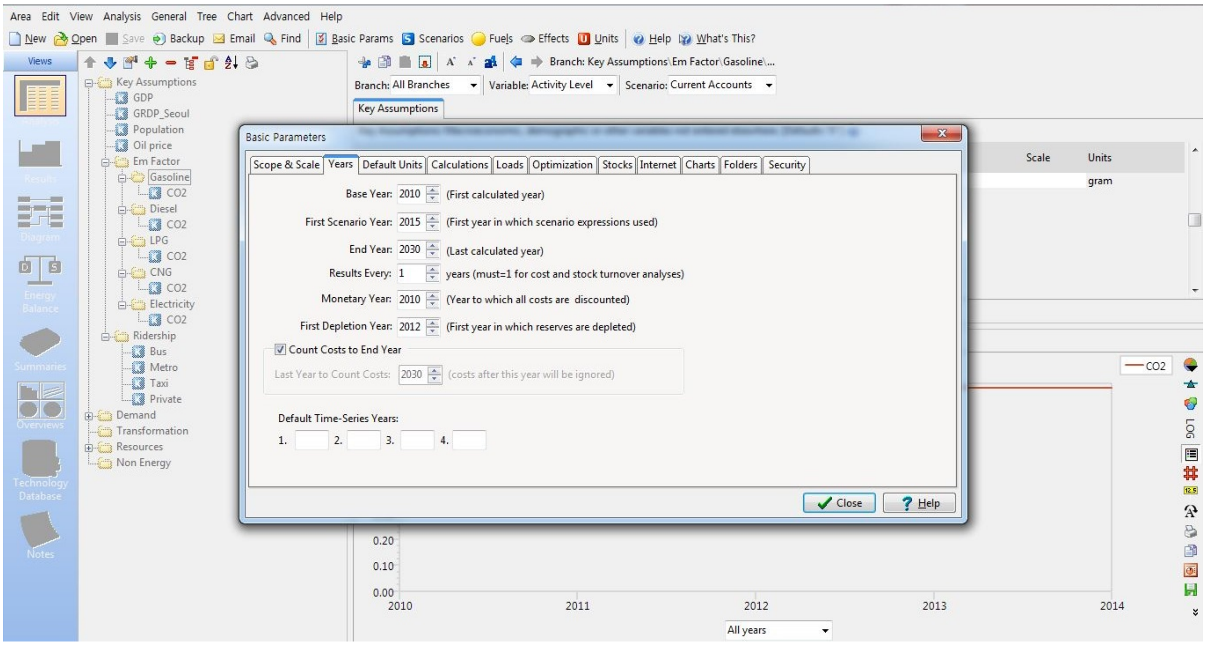

Figure 8 LEAP model Basic Parameter Setting Function

Before data entry, the user must set basic parameters for scenario analysis. This paper set basic parameters as below.

1) *Base Year: 2010*
2) *First Scenario Year: 2015*
3) *End Year: 2030*
4) *Target Years: 2020, 2025, 2030*
5) *Scope: Energy-sector Environmental Loadings*
6) *Default Unit: Energy Unit: Ton of Oil Equivalent*

Monetory Unit: USD

Distance Unit: Kilometer

Environmental Loading: Energy Based: Kg/TOE

Transport Based: Kg/Vehicle-km

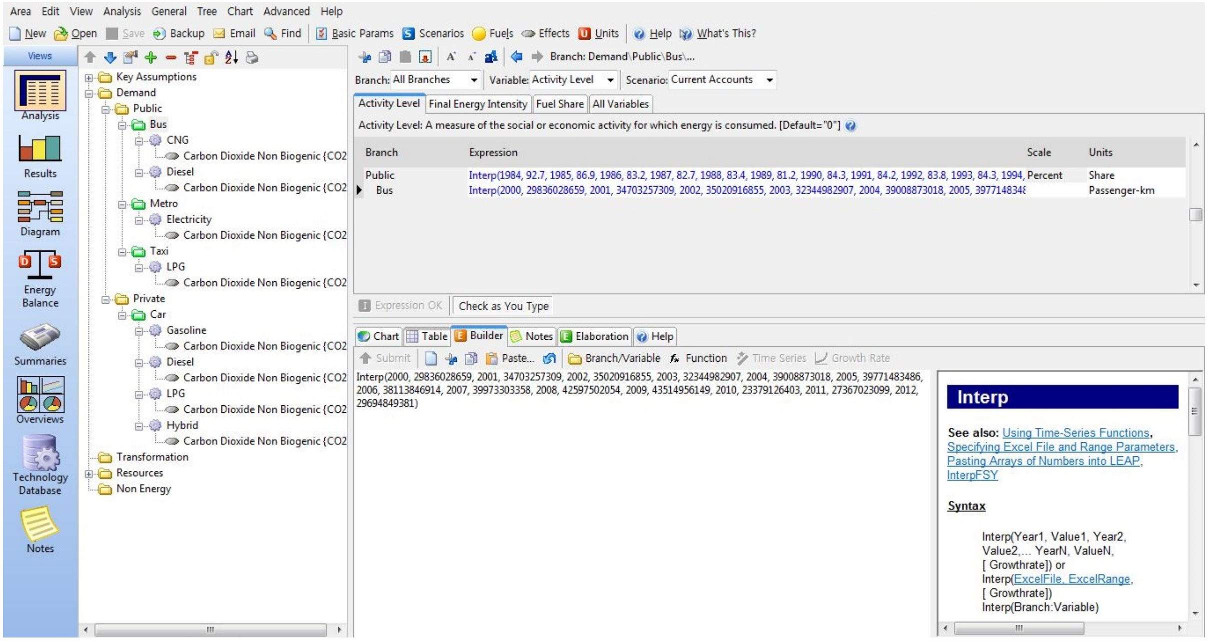

Figure 9 LEAP model Data Input Page

In the Analysis view, the user can create data structures, manage alternative scenarios, and enter data, assumptions and environmental loadings for each fuel. This paper creates a data structure 'Public' and 'Private' and 'Public' divided into 'Bus', 'Metro', and 'Taxi'. Each demand category has fuel type and environmental loading as a sub-branch.

Users can set a growth rate for each data input with various functions (Interpolate, Step Function, Smooth Curve, Linear Forecast, Exponential Forecast, and Logistic Forecast).

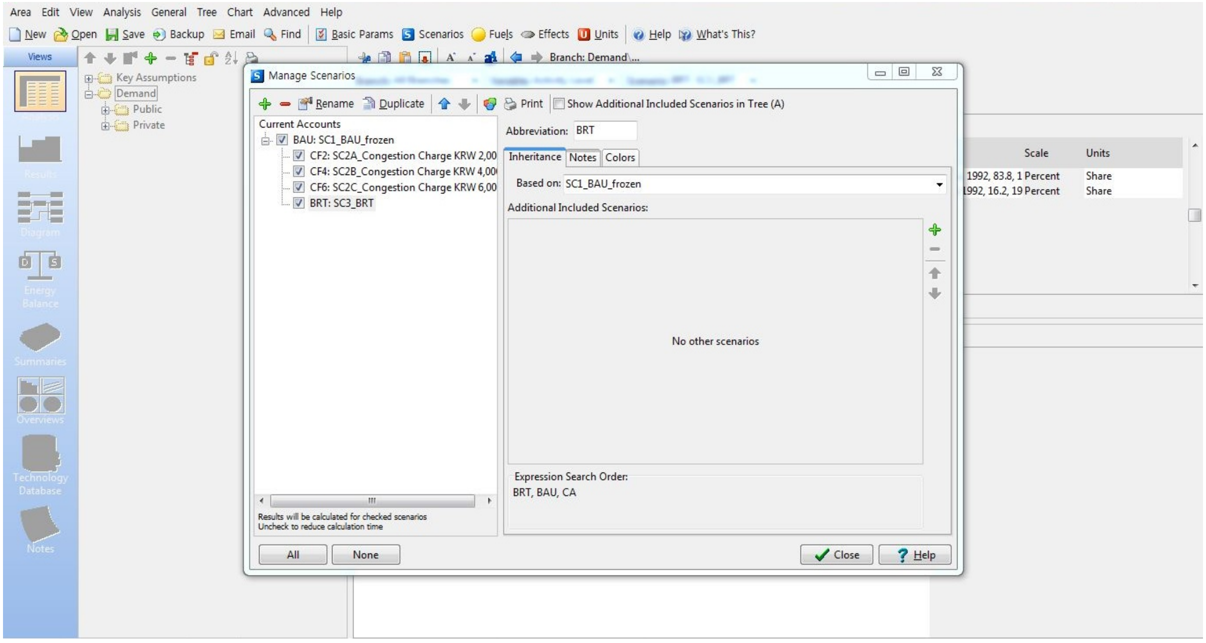

Figure 10 LEAP model Manage Scenario Function

Scenario analysis is the core benefit of LEAP. Scenarios are self-consistent story-lines of how a future energy system might evolve over time in a particular set of policy conditions. The Manage Scenario function enables users to create their own scenarios based on current account. This paper set a business as usual scenario under current account and built congestion charge and bus rapid trasit scenarios under the BAU scenario.

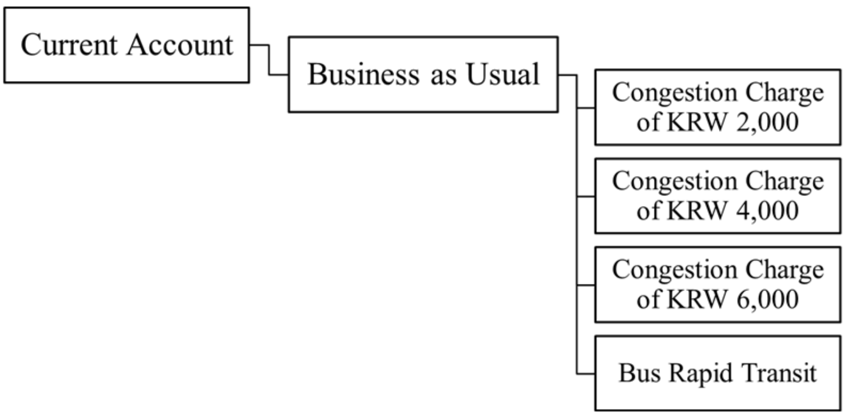

Figure 11 Scenario Hierarchy

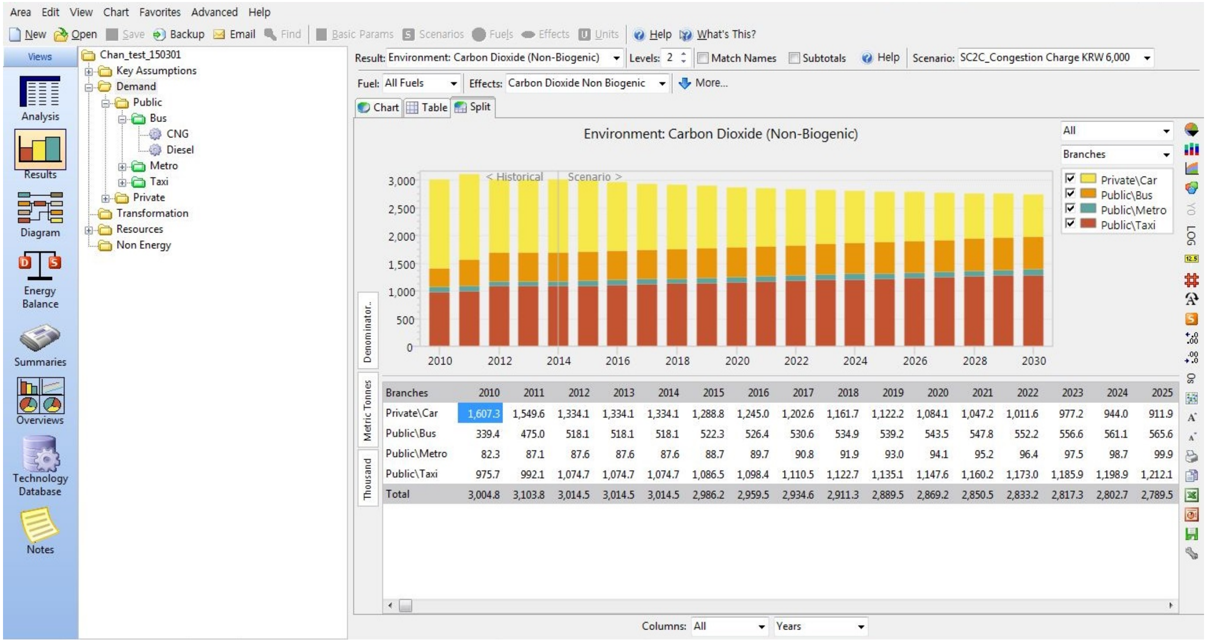

Figure 12 LEAP model Results Page

The Results view is a general-purpose reporting tool for reviewing the results of each scenario calculations in chart, table and other format. Users can use the ‘Results’ selection box at the top of the screen to first pick the category of results and the ‘Scenario’ selection box to pick the scenario.

6 RESULTS

The LEAP model ran alternative scenarios to obtain estimates of transport energy demand and Carbon Dioxide emissions in Seoul metropolitan region from year 2014 to 2030. The results under different scenarios have shown how energy demand and CO_2 emission in the road-passenger transport sector could be reduced by different levels of congestion charge and BRT expansion.

6.1 Results of Scenario 1. (Business as Usual)

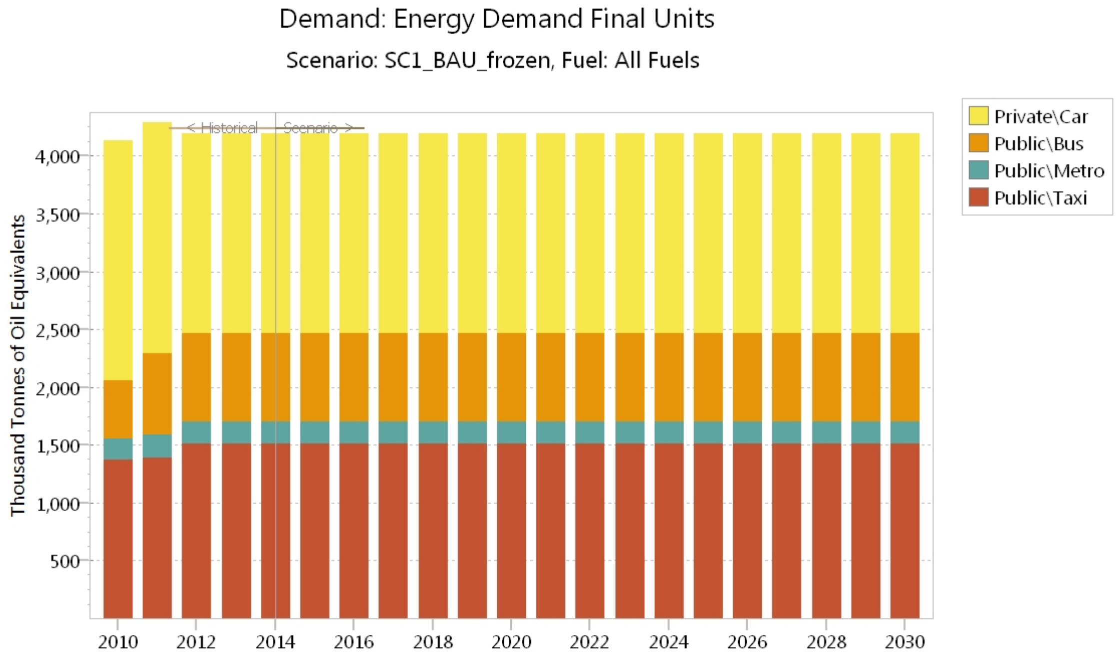

Figure 13 Energy demand by transport mode in BAU scenario

Table 7 Energy demand by transport mode in BAU scenario

Units: Thousand Tonnes of Oil Equivalent

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	2,075.3	1,722.6	1,722.6	1,722.6	1,722.6	1,722.6	1,722.6	1,722.6	1,722.6	1,722.6	1,722.6
Public\Bus	501.3	765.3	765.3	765.3	765.3	765.3	765.3	765.3	765.3	765.3	765.3
Public\Metro	185.9	197.8	197.8	197.8	197.8	197.8	197.8	197.8	197.8	197.8	197.8
Public\Taxi	1,368.4	1,507.3	1,507.3	1,507.3	1,507.3	1,507.3	1,507.3	1,507.3	1,507.3	1,507.3	1,507.3
Total	**4,131.0**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**	**4,192.9**

Figure 14 and Table 7 show the energy demand composition of the business as usual scenario (Scenario 1). Under scenario 1, private passenger vehicles take the largest portion with 41 percent of total energy demand and Taxi is second with 36 percent.

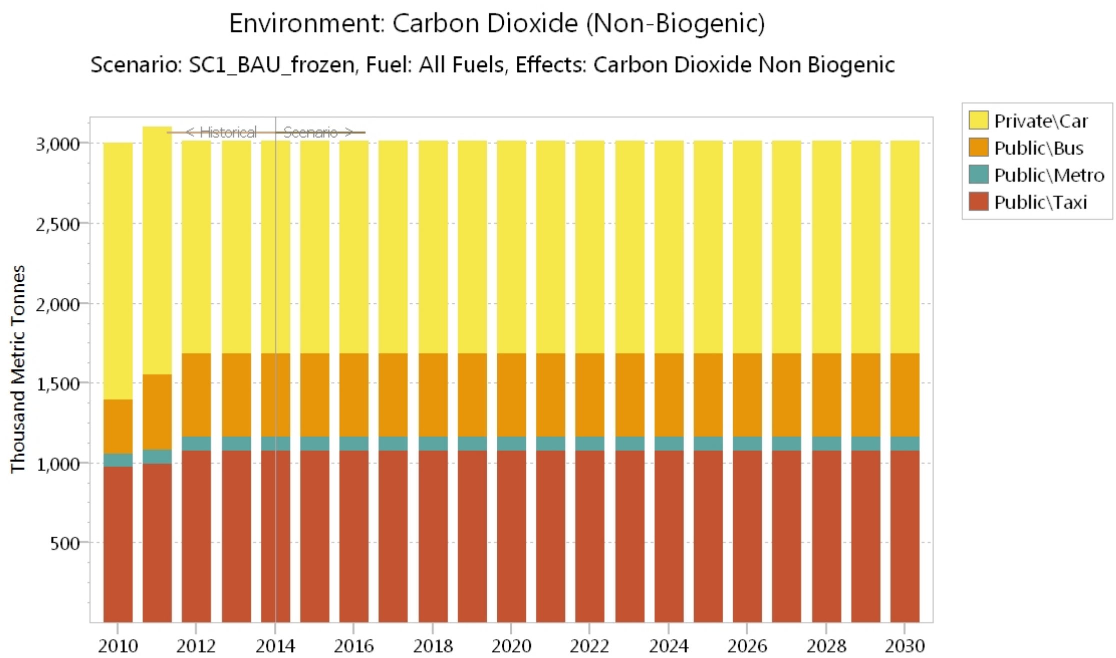

Figure 14 CO_2 emissions by transport mode in BAU scenario

Table 8 CO_2 emissions by transport mode in BAU scenario

Units: Thousand Metric Tonnes

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	1,607.3	1,334.1	1,334.1	1,334.1	1,334.1	1,334.1	1,334.1	1,334.1	1,334.1	1,334.1	1,334.1
Public\Bus	339.4	518.1	518.1	518.1	518.1	518.1	518.1	518.1	518.1	518.1	518.1
Public\Metro	82.3	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6
Public\Taxi	975.7	1,074.7	1,074.7	1,074.7	1,074.7	1,074.7	1,074.7	1,074.7	1,074.7	1,074.7	1,074.7
Total	**3,004.8**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**	**3,014.5**

Figure 15 and Table 8 show the CO_2 emissions composition of the business as usual scenario (Scenario 1). Most of CO_2 emissions comes from private car and taxi demand and metro emits the least CO_2 as it consumes electricity.

6.2 Results of Scenario 2A. (Congestion Charge of KRW 2,000)

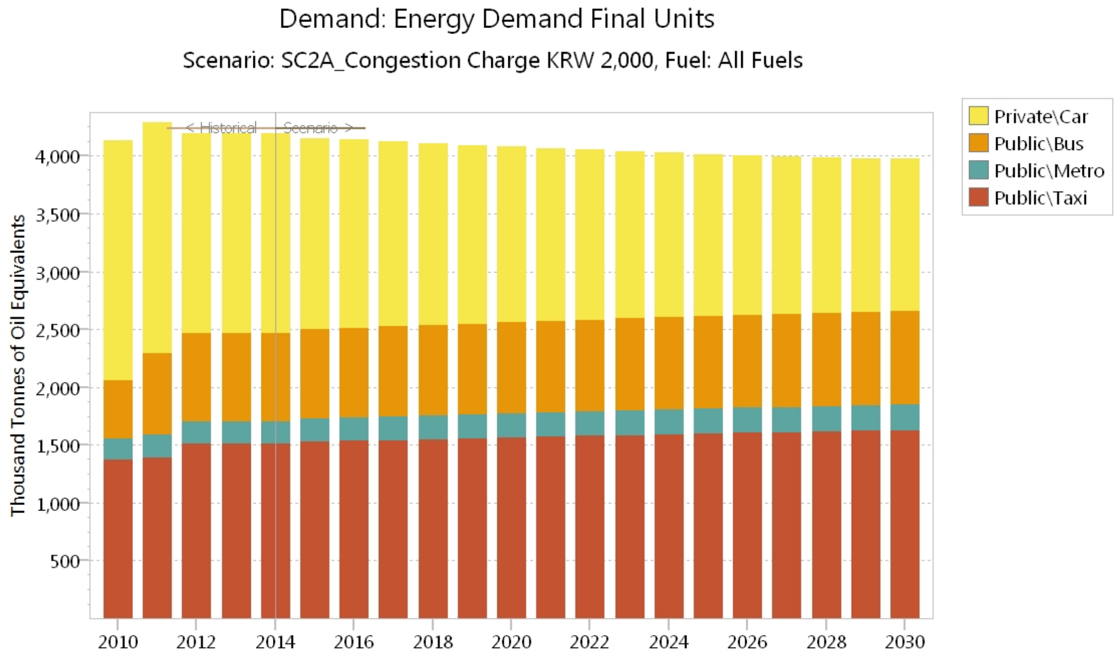

Figure 15 Energy demand by transport mode in congestion charge of KRW 2,000 scenario

Table 9 Energy demand by transport mode in congestion charge of KRW 2,000 scenario

Units: Thousand Tonnes of Oil Equivalent

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	2,075.3	1,722.6	1,722.6	1,626.4	1,571.7	1,518.7	1,469.8	1,422.4	1,381.3	1,346.2	1,312.0
Public\Bus	501.3	765.3	765.3	776.9	782.8	788.8	794.5	800.1	805.0	809.0	813.1
Public\Metro	185.9	197.8	197.8	202.0	204.7	207.5	210.3	213.0	215.6	218.0	220.4
Public\Taxi	1,368.4	1,507.3	1,507.3	1,533.1	1,548.0	1,562.9	1,577.2	1,591.6	1,604.5	1,615.8	1,627.1
Total	**4,131.0**	**4,192.9**	**4,192.9**	**4,138.3**	**4,107.3**	**4,078.0**	**4,051.8**	**4,027.1**	**4,006.3**	**3,989.0**	**3,972.6**

Figure 16 and Table 9 show the energy demand composition of a congestion charge of KRW 2,000 (Scenario 2A). Under scenario 2A, total energy demand shows a downturn trend mainly due to a decrease of private car demand. Slight increases on bus and taxi energy demands indicate that decreasing private car demand shifted to mainly bus and taxi. From 2020, taxi consumes more energy than private car.

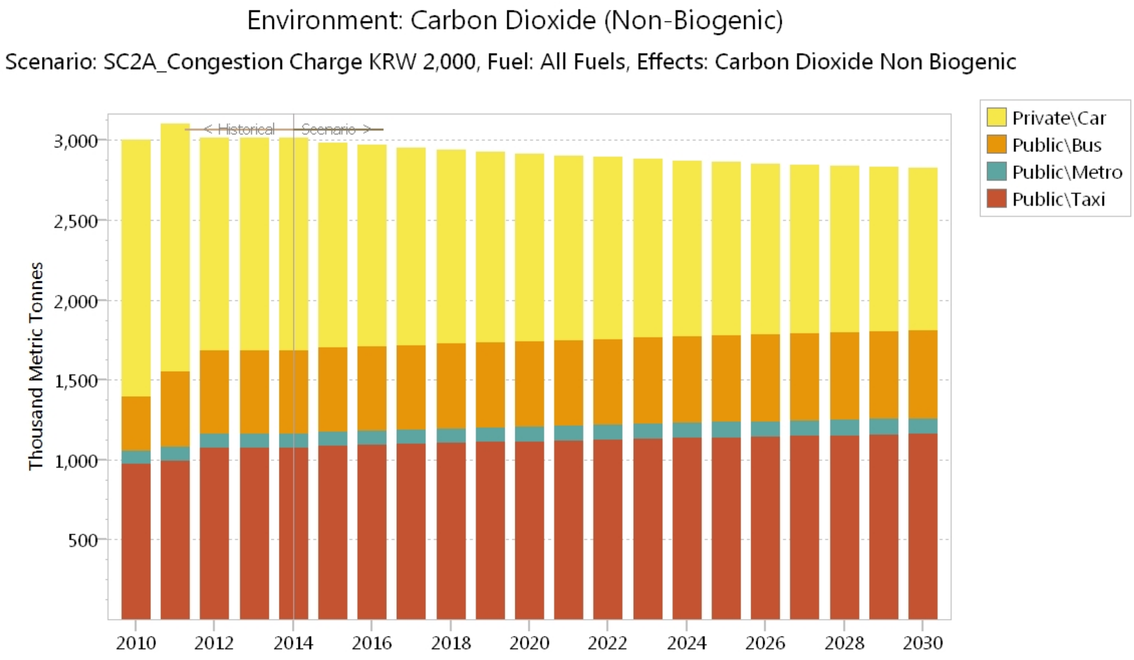

Figure 16 CO_2 emissions by transport mode in congestion charge of KRW 2,000 scenario

Table 10 CO_2 emissions by transport mode in congestion charge of KRW 2,000 scenario

Units: Thousand Metric Tonnes

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	1,607.3	1,334.1	1,334.1	1,259.6	1,217.3	1,176.2	1,138.4	1,101.6	1,069.8	1,042.6	1,016.1
Public\Bus	339.4	518.1	518.1	525.9	530.0	534.0	537.8	541.7	545.0	547.7	550.5
Public\Metro	82.3	87.6	87.6	89.5	90.7	91.9	93.1	94.4	95.5	96.6	97.6
Public\Taxi	975.7	1,074.7	1,074.7	1,093.1	1,103.7	1,114.4	1,124.6	1,134.8	1,144.0	1,152.0	1,160.2
Total	**3,004.8**	**3,014.5**	**3,014.5**	**2,968.2**	**2,941.7**	**2,916.6**	**2,893.9**	**2,872.5**	**2,854.3**	**2,838.9**	**2,824.4**

Figure 17 and Table 10 show the CO_2 emissions composition of the congestion charge of KRW 2,000 scenario (Scenario 2A). The total CO_2 emissions trend shows a downturn mostly due to decreasing demand of private cars.

6.3 Results of Scenario 2B. (Congestion Charge of KRW 4,000)

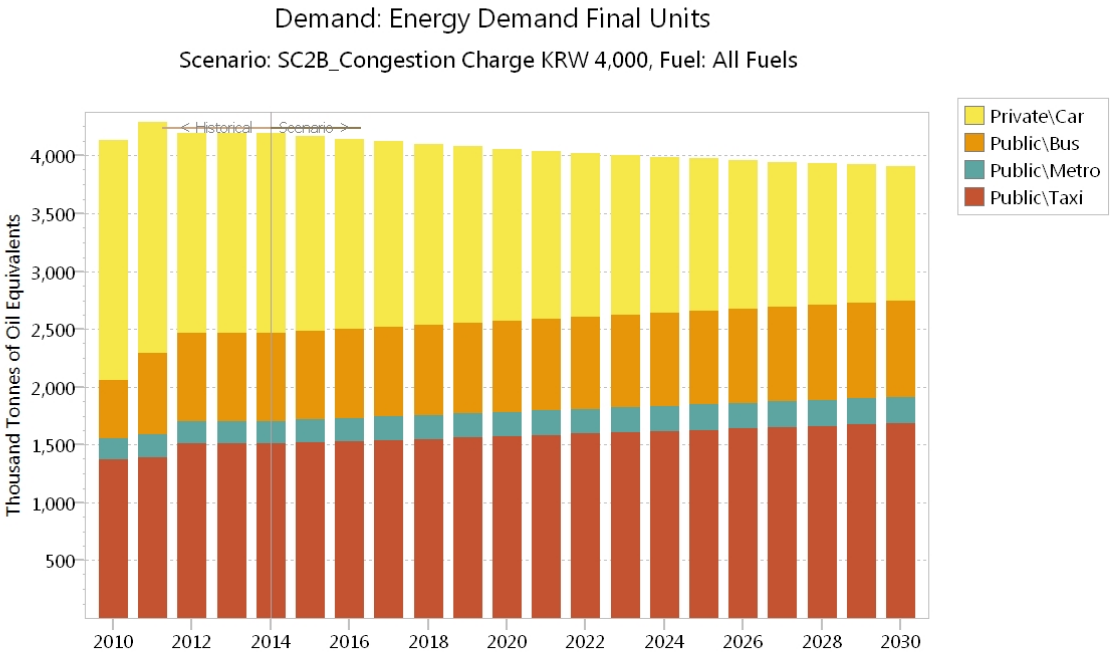

Figure 17 Energy demand by transport mode in congestion charge of KRW 4,000 scenario

Table 11 Energy demand by transport mode in congestion charge of KRW 4,000 scenario

Units: Thousand Tonnes of Oil Equivalent

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	2,075.3	1,722.6	1,722.6	1,640.9	1,563.0	1,488.9	1,418.3	1,351.0	1,287.0	1,225.9	1,167.8
Public\Bus	501.3	765.3	765.3	773.0	780.7	788.5	796.4	804.4	812.5	820.6	828.9
Public\Metro	185.9	197.8	197.8	201.3	205.0	208.7	212.5	216.3	220.2	224.2	228.2
Public\Taxi	1,368.4	1,507.3	1,507.3	1,528.4	1,549.9	1,571.7	1,593.8	1,616.1	1,638.9	1,661.9	1,685.2
Total	**4,131.0**	**4,192.9**	**4,192.9**	**4,143.6**	**4,098.6**	**4,057.8**	**4,021.0**	**3,987.9**	**3,958.5**	**3,932.7**	**3,910.1**

Figure 18 and Table 11 show the energy demand composition of a congestion charge of KRW 4,000 (Scenario 2B). Total energy demand under scenario 2B also decreases. The private car demand shift to bus and taxi is slightly higher than scenario 2A but the point where taxi demand overtakes private car demand is still same (in 2020).

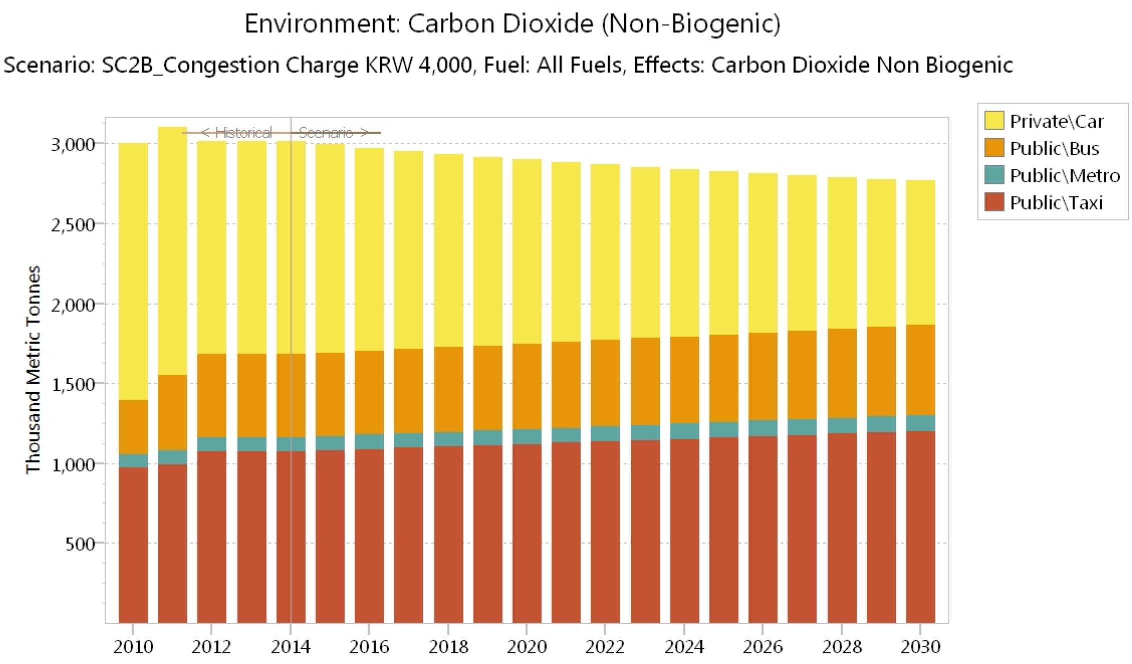

Figure 18 CO_2 emissions by transport mode in congestion charge of KRW 4,000 scenario

Table 12 CO_2 emissions by transport mode in congestion charge of KRW 4,000 scenario

Units: Thousand Metric Tonnes

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	1,607.3	1,334.1	1,334.1	1,270.9	1,210.6	1,153.2	1,098.5	1,046.4	996.8	949.5	904.5
Public\Bus	339.4	518.1	518.1	523.3	528.5	533.8	539.2	544.6	550.1	555.6	561.1
Public\Metro	82.3	87.6	87.6	89.2	90.8	92.4	94.1	95.8	97.6	99.3	101.1
Public\Taxi	975.7	1,074.7	1,074.7	1,089.8	1,105.1	1,120.6	1,136.3	1,152.3	1,168.5	1,184.9	1,201.6
Total	**3,004.8**	**3,014.5**	**3,014.5**	**2,973.1**	**2,935.0**	**2,900.1**	**2,868.2**	**2,839.1**	**2,812.9**	**2,789.3**	**2,768.3**

Figure 19 and Table 12 show the CO_2 emission composition of the congestion charge of KRW 4,000 scenario (Scenario 2B). Private car emissions decreased nearly 30 percent in 2030 compared to 2016. CO_2 emissions from bus and taxi increased slightly to absorb private car demand.

6.4 Results of Scenario 2C. (Congestion Charge of KRW 6,000)

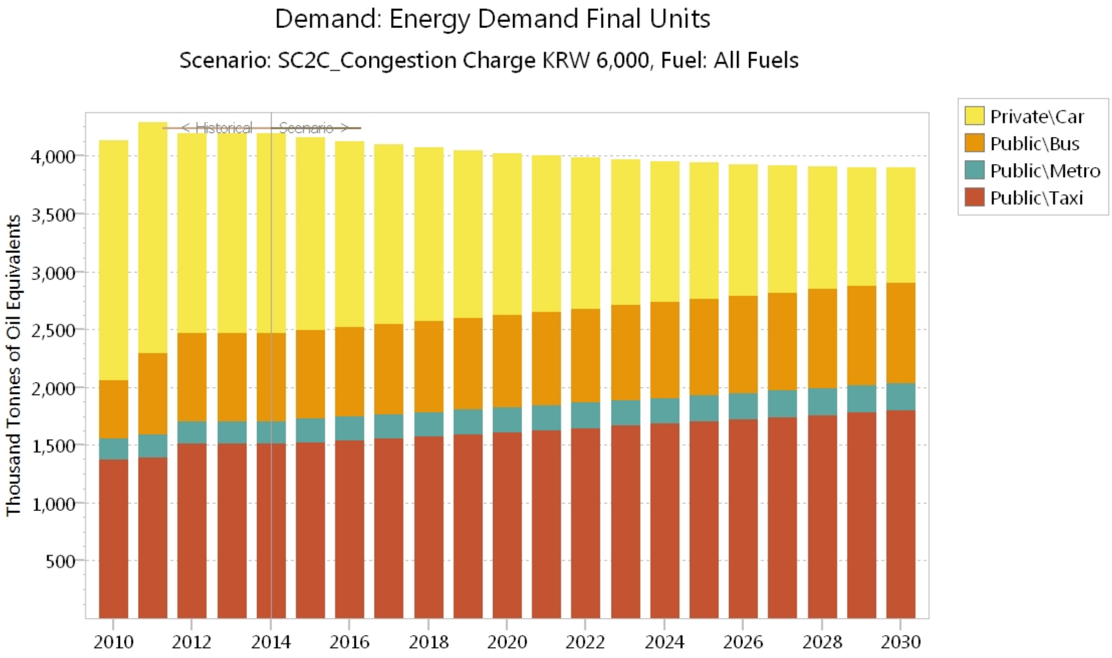

Figure 19 Energy demand by transport mode in congestion charge of KRW 6,000 scenario

Table 13 Energy demand by transport mode in congestion charge of KRW 6,000 scenario

Units: Thousand Tonnes of Oil Equivalent

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	2,075.3	1,722.6	1,722.6	1,607.4	1,500.0	1,399.7	1,306.1	1,218.8	1,137.4	1,061.3	990.4
Public\Bus	501.3	765.3	765.3	777.6	790.1	802.8	815.7	828.8	842.1	855.6	869.4
Public\Metro	185.9	197.8	197.8	202.5	207.4	212.4	217.6	222.8	228.2	233.7	239.3
Public\Taxi	1,368.4	1,507.3	1,507.3	1,540.6	1,574.7	1,609.5	1,645.1	1,681.5	1,718.7	1,756.7	1,795.6
Total	**4,131.0**	**4,192.9**	**4,192.9**	**4,128.1**	**4,072.1**	**4,024.4**	**3,984.5**	**3,951.9**	**3,926.3**	**3,907.4**	**3,894.7**

Figure 20 and Table 13 show the energy demand composition of a congestion charge of KRW 6,000 (Scenario 2C). Under scenario 2C, the private car demand shift to bus and taxi shows significant change. In 2030, private car energy demand sinks to more than half that in 2010. The energy demand of taxi overtakes private car demand in 2018, two years earlier than in the scenario 2A case.

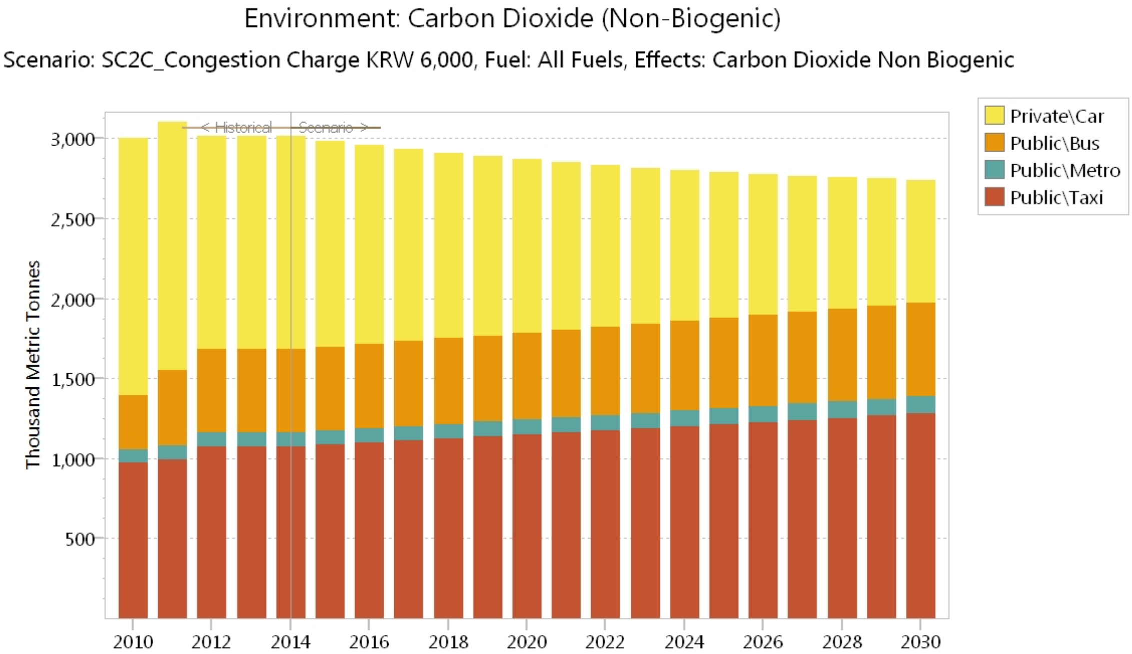

Figure 20 CO_2 emissions by transport mode in congestion charge of KRW 6,000 scenario

Table 14 CO_2 emissions by transport mode in congestion charge of KRW 6,000 scenario

Units: Thousand Metric Tonnes

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	1,607.3	1,334.1	1,334.1	1,245.0	1,161.7	1,084.1	1,011.6	944.0	880.9	822.0	767.1
Public\Bus	339.4	518.1	518.1	526.4	534.9	543.5	552.2	561.1	570.1	579.2	588.6
Public\Metro	82.3	87.6	87.6	89.7	91.9	94.1	96.4	98.7	101.1	103.5	106.0
Public\Taxi	975.7	1,074.7	1,074.7	1,098.4	1,122.7	1,147.6	1,173.0	1,198.9	1,225.4	1,252.5	1,280.2
Total	**3,004.8**	**3,014.5**	**3,014.5**	**2,959.5**	**2,911.3**	**2,869.2**	**2,833.2**	**2,802.7**	**2,777.5**	**2,757.3**	**2,741.9**

Figure 21 and Table 14 show the CO_2 emission composition of a congestion charge of KRW 6,000 scenario (Scenario 2C). Private car demand dropped to nearly half from 2016 to 2030, but the amount of total CO_2 emission reduction is not significant compared to scenario 2B due to increasing demand for taxi and bus.

6.5 Results of Scenario 3. (Bus Rapid Transit expansion)

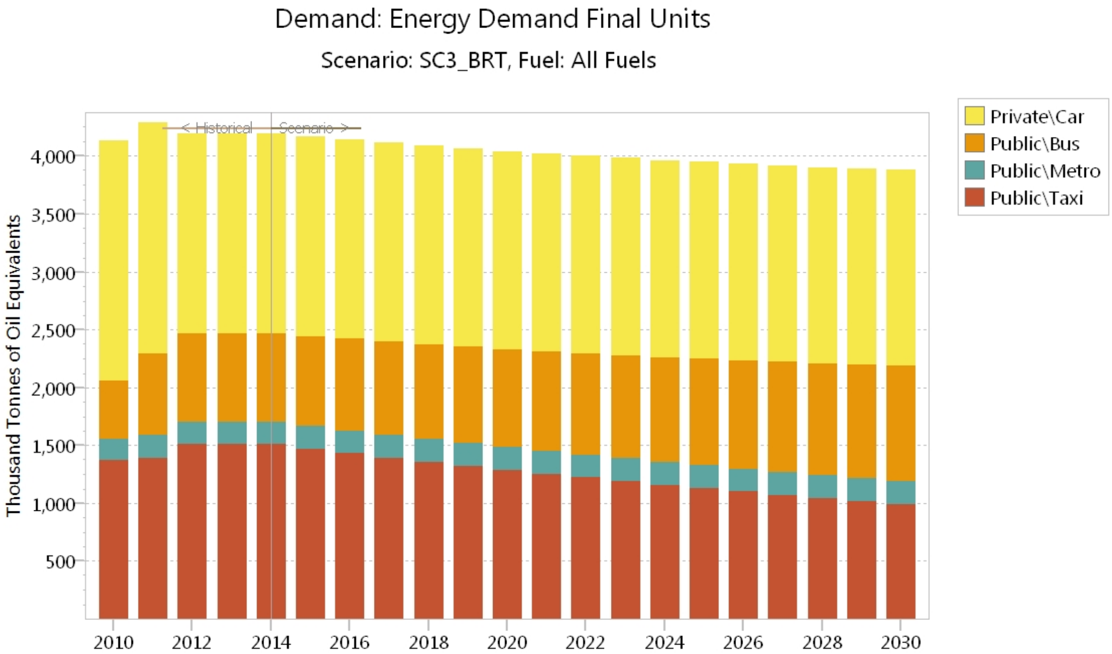

Figure 21 Energy demand by transport mode in BRT expansion scenario

Table 15 Energy demand by transport mode in BRT expansion scenario

Units: Thousand Tonnes of Oil Equivalent

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	2,075.3	1,722.6	1,722.6	1,718.4	1,714.3	1,710.2	1,706.1	1,702.0	1,697.9	1,693.8	1,689.8
Public\Bus	501.3	765.3	765.3	791.5	818.7	846.7	875.8	905.8	936.9	969.0	1,002.2
Public\Metro	185.9	197.8	197.8	197.8	197.8	197.8	197.8	197.8	197.8	197.8	197.8
Public\Taxi	1,368.4	1,507.3	1,507.3	1,429.9	1,356.5	1,286.9	1,220.8	1,158.2	1,098.7	1,042.3	988.8
Total	**4,131.0**	**4,192.9**	**4,192.9**	**4,137.6**	**4,087.2**	**4,041.6**	**4,000.5**	**3,963.7**	**3,931.3**	**3,902.9**	**3,878.6**

Figure 22 and Table 15 show the energy demand composition of BRT expansion (Scenario 3). Under scenario 3, private car energy demand change is not significant, but the energy demand shift from taxi to bus is dramatic. In 2010, the energy demand of taxi was 2.5 times higher than the energy demand of bus, however the energy demand of taxi and bus become almost the same in 2030.

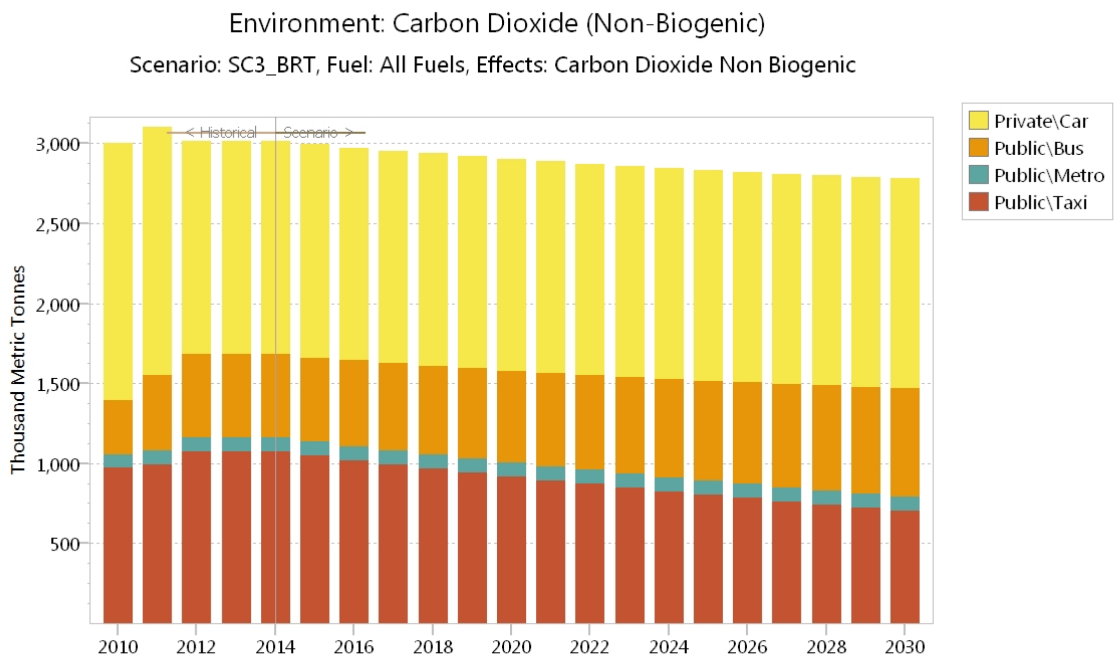

Figure 22 CO_2 emissions by transport mode in BRT expansion scenario

Table 16 CO_2 emissions by transport mode in BRT expansion scenario

Units: Thousand Metric Tonnes

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
Private\Car	1,607.3	1,334.1	1,334.1	1,330.9	1,327.7	1,324.6	1,321.4	1,318.2	1,315.0	1,311.9	1,308.7
Public\Bus	339.4	518.1	518.1	535.9	554.2	573.2	592.9	613.2	634.3	656.0	678.5
Public\Metro	82.3	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6
Public\Taxi	975.7	1,074.7	1,074.7	1,019.5	967.2	917.6	870.5	825.8	783.4	743.2	705.0
Total	**3,004.8**	**3,014.5**	**3,014.5**	**2,973.9**	**2,936.8**	**2,903.0**	**2,872.3**	**2,844.8**	**2,820.3**	**2,798.7**	**2,779.9**

Figure 23 and Table 16 show the CO_2 emission composition of the BRT expansion scenario (Scenario 3). Although a large decrease of CO_2 emissions from taxi demand occurs, increasing emissions from bus and consistent emissions from private cars offset most of its impact.

6.6 Summary of Results

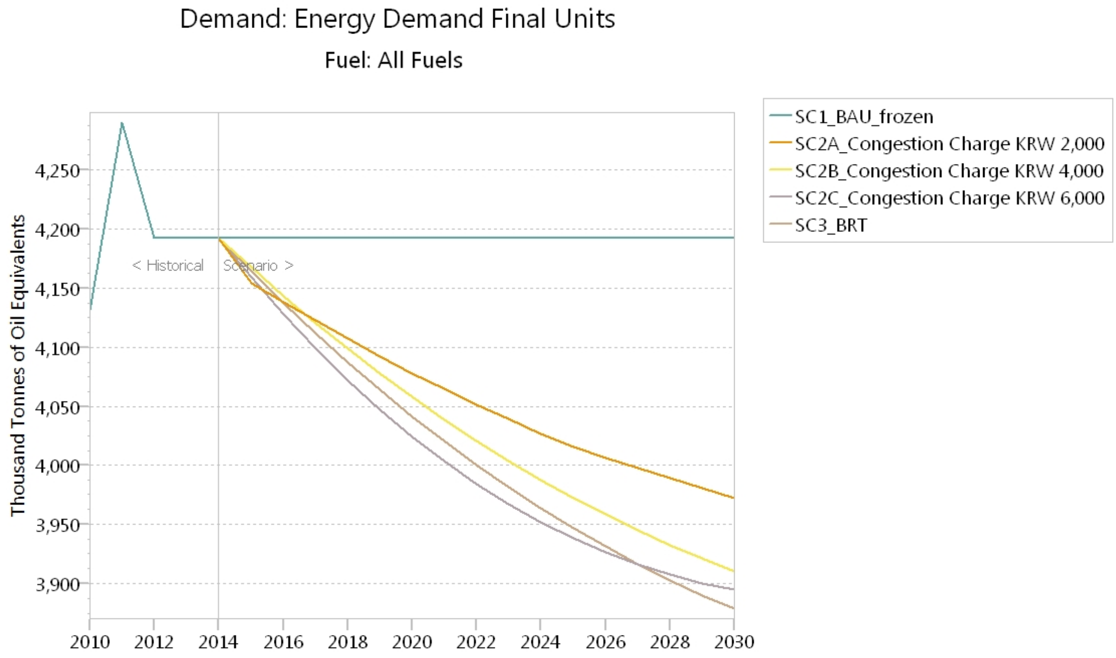

Figure 23 Total energy demands by scenarios

Table 17 Total energy demand by scenarios

Units: Thousand Tonnes of Oil Equivalent

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
SC1	4,131.0	4,192.9	4,192.9	4,192.9	4,192.9	4,192.9	4,192.9	4,192.9	4,192.9	4,192.9	4,192.9
SC2A	4,131.0	4,192.9	4,192.9	4,138.3	4,107.3	4,078.0	4,051.8	4,027.1	4,006.3	3,989.0	3,972.6
SC2B	4,131.0	4,192.9	4,192.9	4,143.6	4,098.6	4,057.8	4,021.0	3,987.9	3,958.5	3,932.7	3,910.1
SC2C	4,131.0	4,192.9	4,192.9	4,128.1	4,072.1	4,024.4	3,984.5	3,951.9	3,926.3	3,907.4	3,894.7
SC3	4,131.0	4,192.9	4,192.9	4,137.6	4,087.2	4,041.6	4,000.5	3,963.7	3,931.3	3,902.9	3,878.6

Figure 24 and Table 17 show the total energy demands of all scenarios. Compared to the BAU frozen scenario, both the congestion charge and BRT scenarios show downturn trends for total energy demand. At the beginning of the scenarios, in 2016, all cases show similar amounts of energy demand decrease. From 2017, scenario 2A shows the smallest rate of decrease among all scenarios and keeps the highest amount of total energy demand up to 2030. Scenario 3 shows the largest amount of total energy demand decrease up to 2027 and after that scenario 2C shows the lowest total energy demand up to 2030.

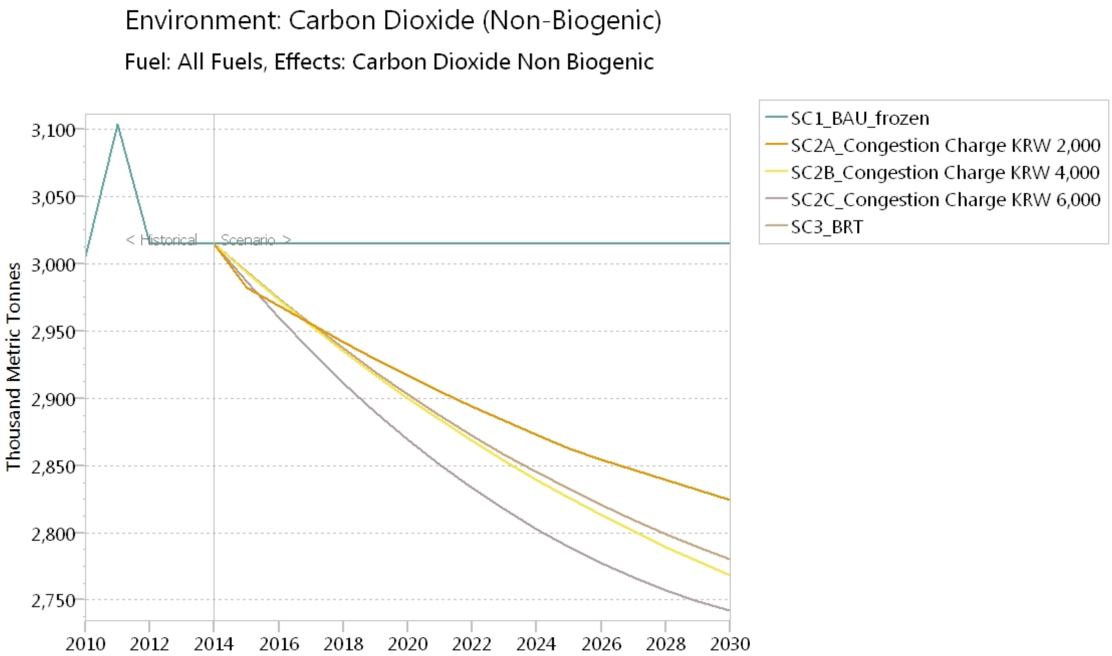

Figure 24 Total CO_2 emissions by scenarios

Table 18 Total CO_2 emissions by scenarios

Units: Thousand Metric Tonnes

Branches	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030
SC1	3,004.8	3,014.5	3,014.5	3,014.5	3,014.5	3,014.5	3,014.5	3,014.5	3,014.5	3,014.5	3,014.5
SC2A	3,004.8	3,014.5	3,014.5	2,968.2	2,941.7	2,916.6	2,893.9	2,872.5	2,854.3	2,838.9	2,824.4
SC2B	3,004.8	3,014.5	3,014.5	2,973.1	2,935.0	2,900.1	2,868.2	2,839.1	2,812.9	2,789.3	2,768.3
SC2C	3,004.8	3,014.5	3,014.5	2,959.5	2,911.3	2,869.2	2,833.2	2,802.7	2,777.5	2,757.3	2,741.9
SC3	3,004.8	3,014.5	3,014.5	2,973.9	2,936.8	2,903.0	2,872.3	2,844.8	2,820.3	2,798.7	2,779.9

Figure 25 and Table 18 show the total CO_2 emission of all scenarios. Compared to the BAU frozen scenario, both the congestion charge and BRT scenarios show downturn trends of total CO_2 emission. The overall trend of total CO_2 emissions by scenario shows a downturn like the total energy demand trend showed previously. Scenario 2C shows the lowest CO_2 emissions from 2016 to 2030 followed by scenario 2B and scenario 3.

7 CONCLUSION

7.1 Discussion

To identify practical solutions for sustainable passenger transport in Seoul metropolitan region, this paper looked at previous research on sustainable urban transport through a literature review. The basic principle of sustainable passenger transport is minimizing energy demand while satisfying transport demand. To comply with this principle, urban passenger transport demand should move toward transport modes with lower energy intensity.

The energy intensity of each passenger transport mode in the Seoul metropolitan region are studied in the analysis part of this paper. The results show that bus and metro have lower energy intensity and private car and taxi have relatively higher energy intensity. Based on energy intensity, passenger transport demand in Seoul metropolitan region should shift to bus and metro.

Among several options for sustainable urban transport, the congestion charge scheme is chosen to control private car use and the bus rapid transit (BRT) option is chosen to promote public transport. This paper developed business as usual, congestion charge, and BRT scenarios to compare the results of each policy option. The LEAP model is used to check energy demand and CO_2 emission changes for each scenario.

The results of the LEAP model show that the congestion charge policy has an effective impact on both energy demand and CO_2 emission reduction by decreasing private car demand. The BRT policy also has an impact on both energy demand and CO_2 emission reduction by absorbing taxi demand, but in the case of CO_2 emission reduction it has inherent limitations due to its marginal impact on private car demand shift.

In conclusion, congestion charge and BRT options are practical solutions to increase the sustainability of passenger transport in Seoul metropolitan region. To maximize its efficiency and effectiveness, this paper suggests a policy package of both options. While reducing private car demand with a congestion charge, BRT expansion would offer an alternative travel option for those who choose public transport rather than private car.

7.2 Implication

This research identifies the carbon intensity of public transport (Bus, Metro, and Taxi) and private car in Seoul metropolitan region to develop sustainable urban transport policy which would reduce total energy use and CO_2 emissions in transport sector. The LEAP model is used to evalute the impact of each scenario on total energy use and CO_2 emissions.

The business as usual scenario in this research has some limitations. To develop the business as usual scenario, a set of basic assumptions is needed such as population growth, GDP growth, technology development, and oil price projections. Due to limited access to such information and time constraints, this research chose business as usual scenario with a frozen condition.

Dispite the limitation, identifying the carbon intensity of transport mode and evaluating transport policy scenarios via LEAP can give implications for developing countries with a growing urbanization trend to keep their cities sustainable. The carbon intensity of transport mode gives a clear signal on which transport mode the city should focus on and the flexibility of the LEAP model enables policy evaluation with minimum data requirements and various policy scenarios.

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