IAEE 2021 online conference

ANALYSIS OF ENVIRONMENTAL EFFECTS OF ELECTRIC VEHICLE DIFFUSION USING THE CGE MODEL

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2021.06.09

1. Introduction

1) Research Background

❖ The diffusion of EV(Electric Vehicles) - a representative policy in reducing GHG emissions and local air pollution in the transportation sector

➢ 17 countries have announced plans to phase out internal combustion engine vehicles (ICEV) and establish 100% zero-emission vehicles by 2050 (IEA, 2020)

- EV sales expectation : 25 million units in 2030, accounting for 16% of all road vehicle sales

➢ Korea government target : 430,000 battery EVs (BEV) and 67,000 hydrogen fuel-cell vehicles (HFCV) by 2022, 33% in new vehicle sales 2030(MOTIE, 2019)

❖ Several studies found mitigation of GHG emissions from EVs, but the results vary depending on the power generation structure

➢ The generation of air pollutants and greenhouse gases by the transportation sector may be reduced by promoting EVs.

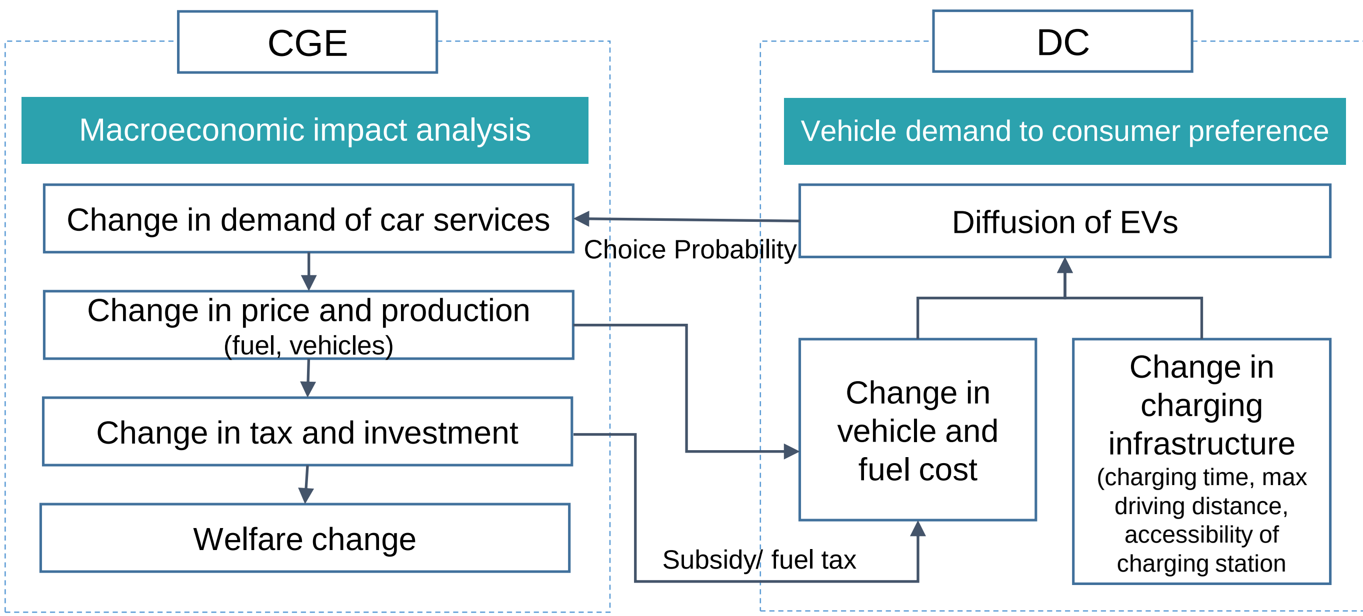
➢ The net effect of EVs can be quantified by considering the emission of air pollutants and greenhouse gases from electric cars and electricity production
→overall industrial structure and energy demand changes

1. Introduction

2) Research Objectives and purpose

❖ Analyzing the economic and environmental effects of changes in the transportation market using Computable General Equilibrium Model(CGE) integrated with Discrete Choice Model(DC)

- CGE : macro-perspective assessment of the changes in the industrial structure
- DC : method investigates consumption behavior from a micro-perspective

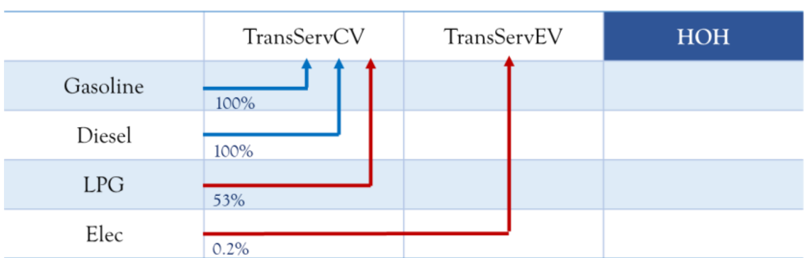


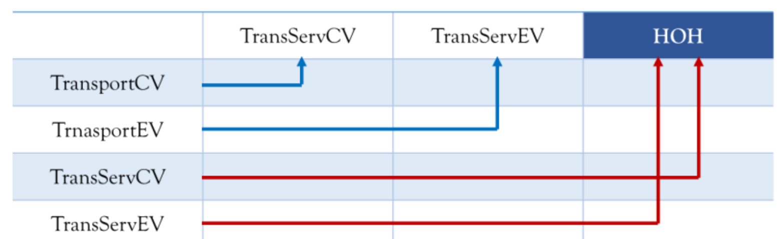
2. Data and Methods

1) Social Accounting Matrix Classification

❖ SAM : the flow of transactions between economic agents in the country

- Construct SAM based on the Bank of Korea’s 2015 IO(Input-Output) table
- SAM was reorganized to reflect new technologies in the transportation market
  - Industries(57), commodities(57), production factors, taxes
  - EV manufacturing sector
  - Transport service divided by vehicle fuel type(Gasoline/Diesel/LPG/Electricity)
  - Transportation services were allocated to independent nests in the household utility function to investigate possible alternatives between transport services





2. Data and Methods

2) CO2 and Air Pollutant Emission Coefficients

❖ Air pollution arises during the production phase while CO_2 is emitted during energy consumption

- Air pollutant emission coefficients (unit emissions) from CAPSS (NIER, 2018)
- CO2 emissions per unit of each industry from energy balance (KEEI, 2018), and the CO2 emission coefficient for energy source (IPCC guideline)

<Examples of air pollutants emission factors by industry>

(unit: ton/billion KRW)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	BC
Transport service	2.846	4.819	0.356	0.155	0.155	0.142	0.619	0.091	0.062
Gasoline ICEV service	6.055	0.971	0.003	0.001	0.001	0.001	0.840	0.533	0.000
Diesel ICEV service	0.446	7.093	0.002	0.119	0.119	0.110	0.147	0.006	0.063
LPG ICEV service	5.505	1.157	0.004	-	-	-	0.173	-	-
Oil refining	0.189	0.170	0.930	0.009	0.003	0.001	0.746	0.312	0.000
Electricity generation	0.859	2.442	1.275	0.303	0.134	0.066	1.012	0.019	0.005
Non-metal manufacturing	0.093	3.308	1.145	0.473	0.265	0.135	0.033	0.003	0.003
1st metal manufacturing	0.095	0.815	0.846	1.103	0.646	0.348	0.207	0.018	0.006

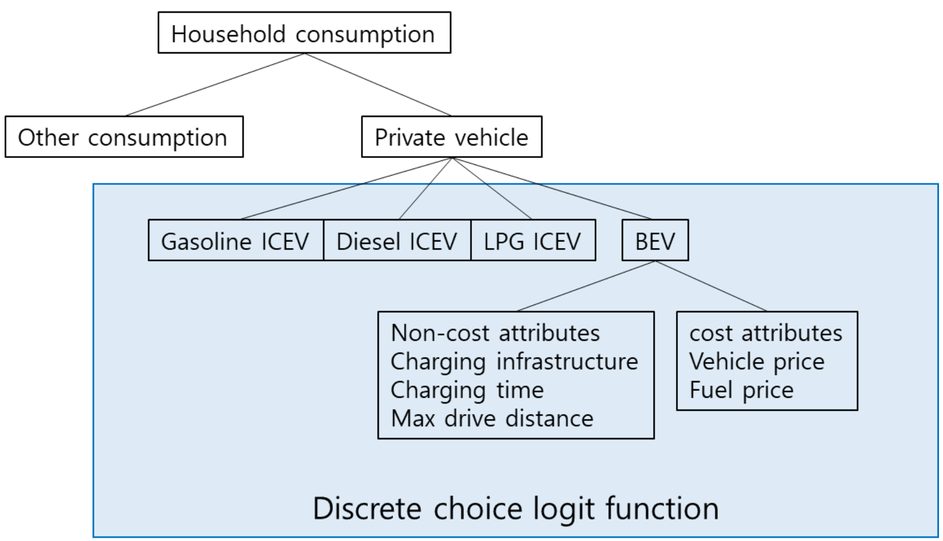
2. Data and Methods

3) CGE model

❖ CGE model structure

- One-country and a year of static model
- KLE(M) - CES structure
- The household consumption function : one representative household has a Cobb–Douglas utility function
- Household demand for automotive services - logit consumption function from DC model

<Private car consumption structure>



2. Data and Methods

4) DC model

❖ Discrete Choice Experiment (DCE): representative methodology used to analyze consumer acceptance and benefits of goods, services or policies

- Based on the probabilistic utility theory, indirect utility ($U_{n,j}$) obtained by the consumer *n* form the alternatives *j* in the choice set
($V_{n,j}$: deterministic utility, $\varepsilon_{n,j}$: stochastic utility)

- Using mixed logit model to reflect the heterogeneity of individual preferences
    - Estimation of Utility Functions for Purchase and Attributes of Vehicles(ICEVs and EVs)
    - $V(indirect\ utility) = \sum \beta_{non-cost\ factors} X_{non-cost\ factors} + \beta_{fuelcost} X_{fuelcost} + \beta_{carprice} X_{carprice}$
    - X = non-cost variables(fuel type, charging time, charging station accessibility, vehicle type, maximum driving distance) and cost variables (fuel cost, vehicle price)
    - Choice probability of transportation service(Ratio of Vehicle Sales by Fuel Type)

$$\Pr[Y_n = j] = \frac{\exp(V_{nj})}{\sum_{k=1}^{J} \exp(V_{nk})}$$

2. Data and Methods

5) Linking DC to CGE Model

❖ Change the household consumption on EVs and CVs reflecting DC results

- Using the choice probability, the household consumption in the vehicle service VQ_j(Vehicle Quantity)

$$VQ_j = \Pr_j \times VTQ$$

- Demand for automobile service estimated from DC method is a physical unit
→ converted into a value unit to be reflected in the CGE model
- Household consumption $XP_j$of automotive service for vehicle purchase and fuel use

$$Xp_j = VQ_j \times pv_j + VQ_j \times pvf_j$$

  - pv_j: vehicle price, pvf_j: fuel price

- The substitution relationship between ICEVs and EVs is considered in the CGE model to adjust the proportion of demand while maintaining the sum of the physical quantity of vehicle services for each type
- By inserting the logit function of the DC method into the CGE model, the effects of non-cost attributes can be confirmed

3. Scenario Description

1) Base scenario

❖ Base scenario - the current automotive technology level and market environment

<Attribute values by vehicle type in the base scenario reflecting DC results>

Attributes	Gasoline ICEVs	Diesel ICEVs	LPG ICEVs	Electric Vehicles
Charging time (unit: hours)	0	0	0	5.3
Access to charging stations(unit: 100%)	1	1	0.1728	0.0478
Fuel price(unit: Korean won/10km)	1,126	921	761	245
Maximum driving distance with one full charge(unit: km)	600	600	400	350
Vehicle purchase price(unit: Korean thousand won)	3,000	3,100	3,100	5,000
Choice Probability	**44.0%**	**25.7%**	**24.9%**	**5.4%**

3. Scenario Description

2) Scenarios

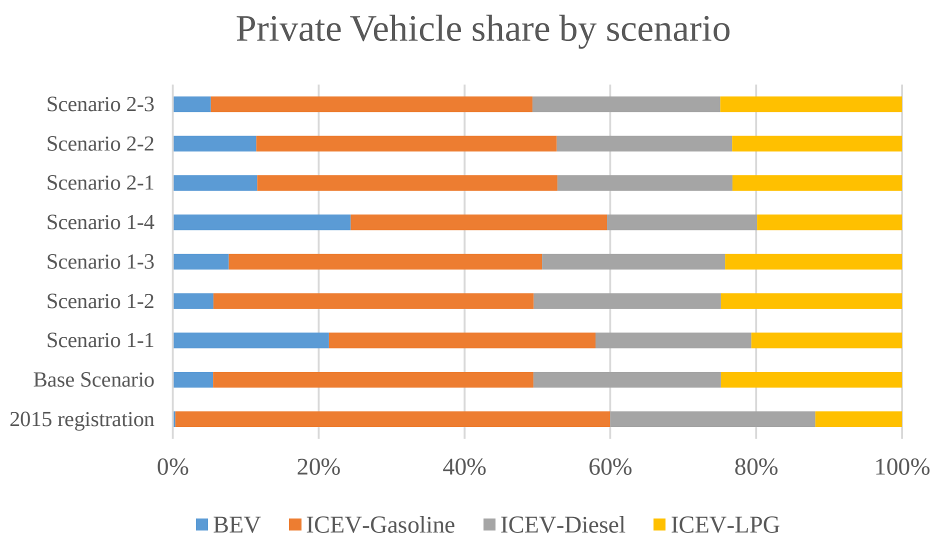
Scenario		Details	
Base scenario		Using the results of choice probability (applied attribute levels by vehicle type)	
Improvement of non-cost factors	Scenario 1-1	Reduced EV charging time	Fast charging standard (1.28)
	Scenario 1-2	Increased accessibility to EV charging stations	15,000 EV charging stations
	Scenario 1-3	Improved EV maximum driving distance	600 km mileage close to CV
	Scenario 1-4	Improved key factors for EVs	(Korean government target) Reduced charging time by 1/3; three-fold increase in accessibility to charging stations; maximum mileage 600 km
Improvement of cost factors	Scenario 2-1	Increased productivity in manufacturing EVs	Reduced value-added and intermediate goods input by about 13%
	Scenario 2-2	EV purchase subsidy payment	Maximum subsidy of 14 million won
	Scenario 2-3	Normalized charging electricity	Electricity rates for charging EVs increased by 40% (178–240 KRW/kW)

4. Scenario Results

1) Changes in Vehicle Demand(1)

❖ Demand for EVs increases by up to 4 times(24.4%) due to improvement in non-cost factors

- ➢ base scenario : a decline in consumption of gasoline and diesel cars compared to a new vehicle sold in Korea in 2015 and shifted the demand for electric cars(5.5%) and LPG cars
- ➢ Technological factors (reduction of charging time) make a significant contribution to increasing demand for EVs (21%)
- ➢ increase in the productivity of the EV manufacturing sector or the payment of EVs subsidy where EVs prices were lowered to the same level as the average price of ICEVs
  → 11.5% EV sales



4. Scenario Results

1) Changes in Vehicle Demand(2)

❖ The transportation fuel consumption changes at the same rate due to changing demands for passenger car services

- Most of gasoline is used in the transportation sector, so changes in gasoline demand in the transport sector have a great influence on the total domestic gasoline use
- Although the power consumption for charging EVs increases three-fold, it does not significantly impact the domestic electricity demand at approximately 2%.

<Change of energy consumption by scenario>

Change of energy consumption	Scenario 1. Improvement of non-cost factors				Scenario 2. Improvement of cost factors		
	Charging time	Accessibility	Max. Distance	All	Productivity	Subsidy	Electricity Price
Gasoline	-9%	-0.021%	-1.3%	-11%	-4%	-4%	0%
Diesel	-2%	-0.004%	-0.2%	-2%	-1%	-1%	0%
LPG	-3%	-0.006%	-0.4%	-3%	-1%	-1%	0%
Electricity	1.5%	0.003%	0.2%	2%	1%	1%	0%
Gasoline use in private car	-16.8%	0.0%	-2.3%	-19.9%	-6.4%	-6.3%	0.3%
Diesel use in private car	-16.8%	0.0%	-2.3%	-20.0%	-6.4%	-6.3%	0.3%
LPG use in private car	-16.8%	0.0%	-2.3%	-20.0%	-6.4%	-6.3%	0.3%
Electricity use in private car	288.1%	0.6%	39.4%	342.1%	110.2%	107.6%	-5.1%

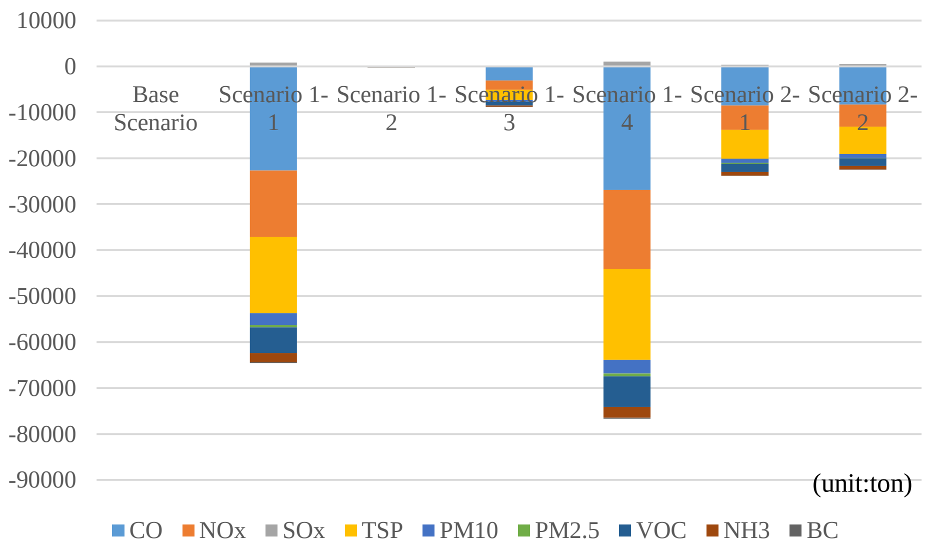
4. Scenario Results

2) Environmental Effects(1)

❖ Overall air pollutant emissions decreased as the spending for EVs increased

- The greatest reduction in CO, NOx, and TSP
- Emission mitigation effects for PM10 and PM2.5 were relatively low, whereas the emission of SOx increased
- The effect of reducing air pollution from the supply of EVs may appear differently because of the difference in the national production and power generation structure

< Air pollutants emission change compared to base scenario>



4. Scenario Results

2) Environmental Effects(2)

❖ Transition of environmental impacts from the driving phase to the production vehicles and electricity phase

- Compared to the change in emissions among the transport sector and the whole industry, the abatement of air pollution in the transport sector was more pronounced, but the CO_2 emissions increased in the country.

< Environmental effects compared to the base scenario>

(unit: ton)

Change in emissions	Scenario 1. Improvement of non-cost factors				Scenario 2. Improvement of cost factors		
	Charging time	Accessibility	Max. Distance	All	Productivity	Subsidy	Electricity Price
CO	-22663	-50	-3100	-26909	-8528	-8300	386
NOx	-14419	-32	-1971	-17122	-5252	-4820	208
Sox	871	2	120	1033	346	488	-29
TSP	-16685	-37	-2280	-19814	-6289	-5987	274
PM10	-2556	-6	-348	-3037	-905	-798	32
PM2.5	-504	-1	-68	-600	-189	-128	4
VOC	-5570	-12	-763	-6612	-1806	-1670	64
NH3	-1994	-4	-273	-2368	-793	-747	35
BC	-186	0	-25	-221	-63	-59	2
Transportation	-67294	-148	-9207	-79897	-25729	-25135	1187
Total	**-63706**	**-140**	**-8709**	**-75650**	**-23480**	**-22021**	**978**
CO2	274257	558	35173	330026	356730	317819	-22578

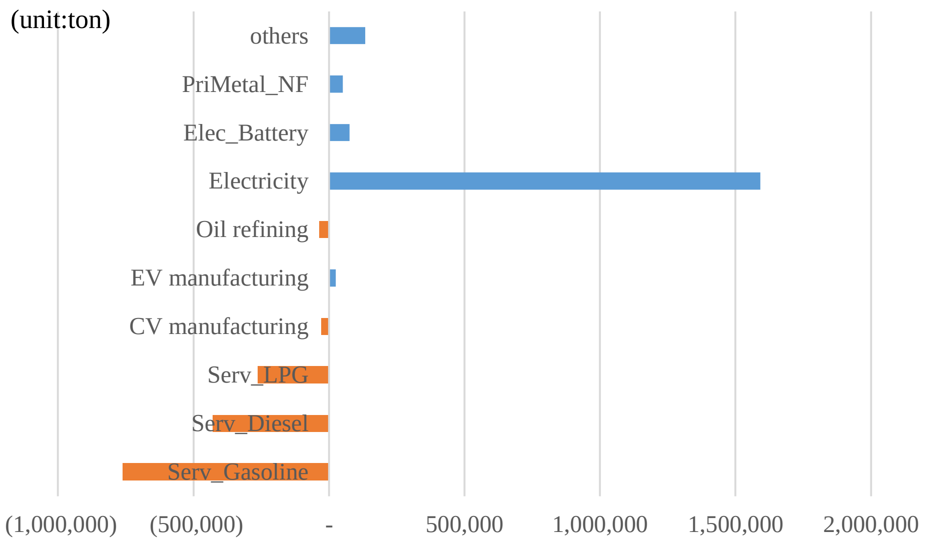
4. Scenario Results

2) Environmental Effects(3)

❖ CO_2 emission increase as a whole industry

➢ Reduction in the cost of household passenger car consumption leading to an increase in other sectors consumption

<CO2 emission change by sector in scenario 2-1 compared to the base scenario>



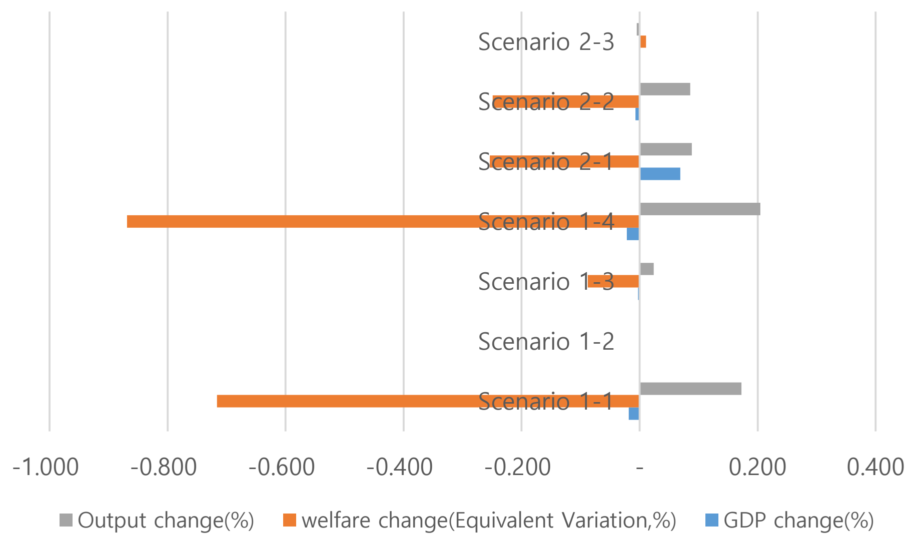
4. Scenario Results

3) Economic Effects

❖ Total output increased but GDP and welfare decreased according to the diffusion of EVs

- Decline in the production of conventional vehicle manufacturing and oil-refining industries from the diminishing demand for ICEVs service offsets the effect of the rise in battery and EV production to the increase in EVs demand
- GDP increased in only scenario 2-1 when EV productivity progressed

<Economic effects compared to base scenario>



5. Conclusion

- Through the CGE model, the net result of the proliferation of EVs in the nation as well as in the transportation sector can be indicated by observing the industrial linkage effects caused by the increase in EV production and demand
  - The effect of reducing air pollution in the transportation sector caused by internal combustion locomotives was downscaled when it was expanded to the whole industry
  - The environmental effects of electric cars are heavily influenced by the power mix supplied to EVs
  - It is more economically practical to increase the productivity of EV production through research and development investments than to induce consumers to purchase by providing subsidies through the EV supply policy.

- Both the economy and environment will benefit only when a policy for spreading EVs based on a clean power mix and improving productivity is carried out

Thank you for listening