# Decarbonizing Road Transportation in Korea

# : A Policy Analysis Using an Integrated Computable General Equilibrium Model

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Abstract

The transportation sector, particularly road transport, is among the largest emitters of greenhouse gases (GHG) and requires effective policies to achieve net-zero emissions by 2050. To address this, the Korean government has implemented various policy tools aimed at decarbonizing the road transportation sector, including improving the fuel efficiency of internal combustion engine vehicles (ICEVs), electrifying transport modes, and managing private vehicle demand. Our work focuses on analyzing the effects of these policy tools on the Korean road transport system, economy, and environment. To this end, we developed an integrated Computable General Equilibrium (CGE) model that incorporates vehicle dynamics and vehicle choice mechanisms. Our findings show that traditional carbon pricing alone is insufficient to achieve net-zero targets, and instead, targeted policy tools such as EV subsidies and managing private vehicle demand through VMT taxes are necessary. Furthermore, these policy tools can promote the growth of new EV manufacturing industries and help limit atmospheric pollution emissions from ICEVs, thereby improving the environment. As Korea and other developing countries face similar challenges in decarbonizing their road transportation sectors, our policy analysis can provide valuable insights and strategies for achieving net-zero emissions in this sector.

## 1. Introduction

### 1.1 Net-zero emission of transportation sector

Over 70 countries have committed to achieving net-zero emissions, and the transportation sector is a crucial component of this objective. Globally, the transport sector accounts for approximately 15% of greenhouse gas emissions, with almost 8.7GtCO2 generated by this sector (IPCC, 2022). While the COVID-19 pandemic led to a temporary reduction in emissions, the transportation sector has witnessed a rebound in emissions as the pandemic comes to an end (IEA, 2022). To mitigate emissions from the transportation sector, a shift towards low-emitting modes of transportation is of utmost importance (UNEP, 2022).

The road transport sector is responsible for the largest share of emissions in the transportation sector, accounting for more than 72% of all transport emissions. Previous literature suggests three key strategies to reduce GHG emissions in the road transport system. Firstly, there is a need to phase out conventional Internal Combustion Engine Vehicles (ICEVs) as even with biofuels and other alternative fuels, it is not possible to fully decarbonize ICEVs (ZEVTC, 2021). Therefore, an urgent transition to Electric Vehicles (EVs) is necessary. Secondly, there is a need to shift short- and medium-distance travel modes from private vehicles to other modes of transportation such as public transport and bicycling (Boehm et al., 2022). Lastly, improving fuel and energy efficiency is crucial for reducing CO2

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emissions in the road transport sector. Energy efficiency plays a significant role in lowering GHG emissions, as evident from the EU case (EEA, 2022).

### 1.2 Korea's transportation policies for the net-zero target

Based on data from Climate Watch, as of 2019, the Republic of Korea (hereafter referred to as Korea) was ranked as the 14th largest emitter of greenhouse gases (GHGs) in the world, and one of the fastest-growing emitters due to economic growth over the past 30 years. Since 2015, Korea has been actively working towards reducing emissions. The Korean government announced an ambitious target of achieving carbon neutrality by 2050 in 2021, making it the 14th country to enshrine this goal into law through the Carbon Neutrality Act (MOE, 2021).

In recent years, total greenhouse gas (GHG) emissions in Korea have reached their peak and have slowly decreased since then. However, decarbonization in transportation sector have remained stagnant. Since 2018, the transportation sector's GHG emissions have only decreased by 0.02% until 2021, and it is projected to increase post-pandemic. The Carbon Neutrality Act mandates that the transportation sector reduce its emissions by 37.8% from 2018 levels, the third-largest reduction target among all sectors, behind waste management and power generation. In 2018, the transportation sector emitted 98.1 million $tCO_2$, accounting for 13.5% of total GHG emissions in Korea. Road transport, which accounts for 97% of emissions from the transportation sector, is the largest emitter of $tCO_2$, with emissions totaling 94.7 million $tCO_2$.

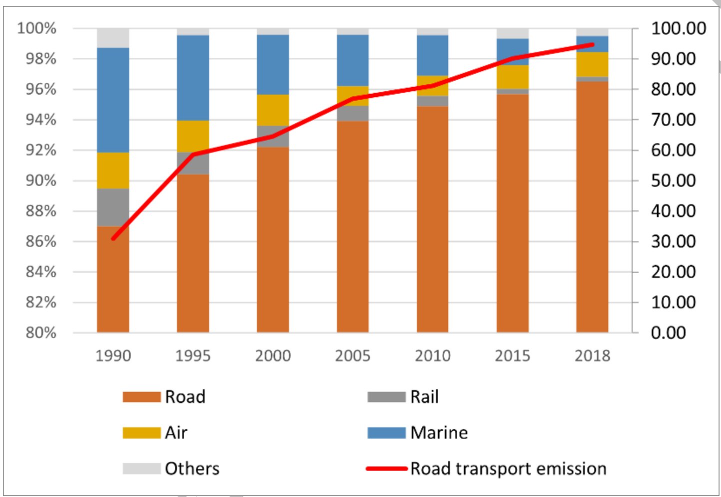


**Figure 1 Emission ratio by modes (left) and GHG emissions of road transport (right) in Korea**

(Data source: KOTEMS).

The Korean government has implemented a range of strategies to reduce greenhouse gas (GHG) emissions in road transport, as part of its efforts to achieve carbon neutrality by 2050. The "2030 NDC" initiative focuses on demand management, behavior improvement, and increasing the supply of electric vehicles (EVs) as key strategies for reducing GHGs. Additionally, the "2050 Carbon Neutrality Scenario" aims to reduce passenger traffic by 15% and electrify at least 85% of road vehicles by 2050.

The Korean government has also proposed the "2050 Carbon Neutral Roadmap for Land, Infrastructure and Transport," which prioritizes two major strategies: accelerating the supply of electric and hydrogen vehicles and enhancing public transportation to decrease private demand. To achieve this goal, the government plans to supply up to 4.5 million electric and hydrogen vehicles by 2030, with purchase incentives being provided. Additionally, public transportation will play a significant role in decreasing vehicle demand.

The main strategies of these plans can be categorized into three types: improving the fuel efficiency of new internal combustion engine vehicles (ICEVs), electrifying transportation modes by replacing ICEVs with EVs, and controlling demand to reduce vehicle kilometers traveled (VKT).

| Plan | Strategy | Explanation |
|---|---|---|
| 2030 NDC | Demand management | Reducing the mileage of motor vehicles, such as improving the convenience of public transportation(4.5% reduction compared to 2018 by 2030) |
| | Supply of eco-friendly cars | Supply of 4.5 million eco-friendly cars |
| | Behavior improvement | Energy saving by enhancing eco-friendly driving behavior |
| 2050 Carbon Neutrality Scenario | Strengthening demand management | Reduce passenger traffic by 15% through public transportation and personal mobility |
| | Electrification and hydrogenation of road sector | Electrification and hydrogenation of the road sector (A) or the use of alternative fuels for some residual internal combustion vehicles (B) |
| 2050 Carbon Neutral Roadmap for Land, Infrastructure and Transport | Accelerate the supply of electric and hydrogen cars | Cumulative supply of 4.5 million electric and hydrogen cars (2030)<br>Purchase incentives (support for the difference in purchase price with internal combustion vehicles) |
| | Enhancing public transportation | Demand management for private vehicles by enhancing public transportation |
| 4th Basic Plan for Eco-friendly Cars (2021~2025) | Accelerate the spread of eco-friendly cars | Reducing automobile greenhouse gases by 24% by 2030 through the spread of eco-friendly cars<br>Cumulative supply of eco-friendly vehicles 2.83 million (2025) and 7.85 million (2030) |
| 2nd Basic Plan for National Transportation Logistics Development (2021-2030) | Major conversion to eco-friendly cars | Cumulative supply of 4.5 million electric and hydrogen vehicles (2030) |
| | Tightening of fuel economy standard for Automobiles | Tightening greenhouse gas and fuel efficiency standards for passenger cars and vans<br>GHG: 97k/km('20) → 70g/km('30)<br>Fuel efficiency: 24.3km/l('20) → 33.1km/l('30) |
| | Strengthening the energy saving public transportation | Reducing the mileage of private cars by 4.5% and promoting the use of public transportation through traffic demand management |
| Comprehensive Plan for Fine Dust Management (2020~2024) | Accelerating the abolition of old diesel vehicles | Early abolition of old diesel vehicles |
| | Suppressing the demand for new diesel | Adjustment of the relative price of energy for transportation |

| | | |
|---|---|---|
| | cars | |
| | Expansion of low pollution vehicles | 850,000 electric vehicles and 150,000 hydrogen cars by 2024 |
| | Promoting public transportation convenience and managing transportation demand | Improvement of public transportation convenience |

**Table 1 policy tools proposed in major transportation plans in Korea**

### 1.2 Objective of the research

This study presents a national economic model that links a dynamic vehicle stock model with a top-down CGE model to analyze the impact of transportation tax reform on the market share of EVs, as well as economic and environmental effects in Korea. Our approach has three distinctive features compared to previous studies.

Firstly, our model includes technical developments in modeling the transportation sector. We use a nested CES structure to capture the substitution effect between vehicle fuel types, new-vintage vehicles, and private-public transport, enabling us to simulate the vehicle choice mechanism of different fuel types and vintages. Moreover, we incorporate dynamics of vehicle stocks to analyze the effect of vintage vehicles. For this analysis, we collect vehicle registration data according to fuel type and calculate the survival rate of vehicles in Korea. From this, we incorporate different lifetimes and scrap rates of vehicles by fuel type and build fuel-type-specific stock dynamics of vehicles.

Secondly, we consider various policy tools to meet the transition target in the net-zero plan. We find that achieving the EV transition target and decarbonizing the road transportation sector is challenging without strong policy tools. Our model confirms that current ETS has little effect on mode transition, and we suggest appropriate policy tools to shorten the transition to a low-emission transportation system and minimize negative economic effects.

Lastly, we consider the effect of transportation tax reform strategies for GHG reduction in the transportation sector, specifically, strengthening fossil fuel tax and implementing VMT tax. Although some studies have raised concerns that VMT tax may deter EV deployment, our study shows that it has little impact on EV deployment and can have a positive effect on the environment through reducing the distance traveled. We analyze the economic and environmental effects of these strategies and propose an appropriate and feasible policy mix to simultaneously minimize economic damage and achieve policy goals.

These results can apply not only to Korea but also to other countries that aim to achieve net-zero targets in the transportation sector. Given the challenges that Korea and other developing countries face in decarbonizing the road transportation sector, the policy mix proposed in this paper may be helpful.

## 2. Literature review

### 2.1 CGE for transportation system modelling

Computable General Equilibrium (CGE) modeling has emerged as a useful tool for evaluating the economic and environmental effects of policies, particularly in the transportation sector. Previous literature has utilized CGE models to analyze the sector, including the well-known MIT EPPA model developed by researchers at MIT. This comprehensive model considers the interactions between energy, economy, and environment, allowing policymakers to assess the impact of various policy options in achieving climate and energy goals while considering potential economic and social impacts.

Several studies have proposed methods to incorporate the complexities of the transportation sector into CGE models. Karplus et al. (2013) developed a model that integrates engineering and fleet details, such as vehicle powertrain technologies, fuel efficiency, and weight, as well as consumer preferences for vehicle attributes. This allows for the analysis of the economic impacts of various policies related to passenger vehicle transport.

Similarly, Schmelzer et al. (2018) proposed a methodology for incorporating electric vehicles (EVs) into a CGE model. This hybrid model combines a detailed model of the German energy system with a macroeconomic model of the German economy to evaluate the economic impacts of policies aimed at promoting the adoption of EVs.

Waisman (2013) explored a range of policy options to reduce emissions, including promoting alternative fuel vehicles and increasing public transportation usage. The paper analyzed the potential impacts of these policies, including the creation of new jobs and industries, using the IMACLIM-R model to evaluate their impact on the transportation sector and the wider economy.

Finally, for a case study of Korea, Lee and Koo (2023) empirically analyzed the effect of alternative fuel vehicles on $CO_2$ emissions and the national economy. They utilized a discrete choice (DC) model to quantify the effect of individual vehicle choices on the overall economy using a CGE model. The authors showed that the replacement of internal combustion engine vehicles (ICEVs) with alternative fuel vehicles may decrease $CO_2$ emissions in the transportation sector, but may also have unintended effects due to the increased production of other industries.

## 3. Methods and data

### 3.1 Data

#### (1) Social accounting matrix classification

In this study, we utilize the Input-Output table of the year 2019 published by the Bank of Korea (BOK, 2019) to construct the Korean version of the Social Accounting Matrix (SAM). The original table contains 381 commodities, which we consolidate into 42 categories, including goods and services, production factors, taxes, and final demand. This SAM is directly integrated with the GTAP10 database to enable a comprehensive analysis of the global economy.

To capture the unique input-output structure of ICEVs and EVs, we incorporate a transportation I/O model developed by Shin (2022). This model separates the input structure of ICEVs and EVs and facilitates the analysis of the vehicle stock model by vehicle type. Furthermore, we disaggregate the current petroleum product manufacturing industry into gasoline, diesel, and other products, corresponding to their respective use in vehicles. As electricity is a crucial fuel source for EVs, we differentiate the power generation sector into fossil fuel, nuclear, and renewable sources. We employ the input structure of the year 2019 provided by Shin (2022) for this purpose.

#### (2) Vehicle data

In Korea, vehicle categorization varies across different data sources. The Ministry of Land, Infrastructure and Transport provides vehicle stock data that is categorized by private, commercial, and government use, while the Korea Statistics agency provides vehicle travel distance data that is separately classified for business and non-business purposes. For this study, we focus specifically on private consumption vehicles among all passenger vehicles.

To obtain specific vehicle stock data, we rely on the Korea Automobile Manufacturers Association (KAMA) for the reference year of 2019. We calculate the stock data by fuel type and vintage and find that gasoline vehicles account for 67.6% of all private vehicles, with this proportion increasing for older vehicles due to the longer average lifespan of gasoline vehicles compared to diesel vehicles. As of 2019, EVs represented less than 0.5% of the total vehicle stock. However, the deployment of EVs is growing rapidly, with EVs accounting for 2% of vehicles that were purchased less than a year ago.

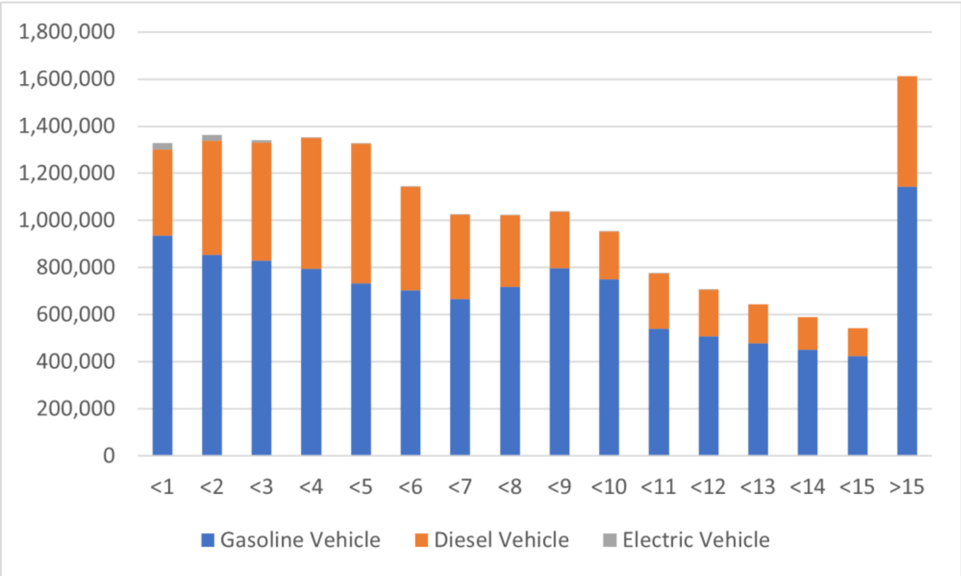


**Figure 2 Vehicle stock by fuel type**

(3) Survival function of vehicle

The survival rate of a vehicle is primarily dependent on its age. To calculate this rate, we utilize a logistic survival function as proposed by Miaou (1995). We make the assumption that scrappage follows a Bernoulli distribution, whereby the probability of a vehicle being scrapped at time t is given by the following expression:

$$P\left(Z_{t,m,i} = 1\right) = \frac{1}{1 + \exp(\alpha + \beta\ AG_{t,m,i})}$$

(Where, Z: whether the i vehicle registered in year m has been scrap at time t (1) or still remains (0), AG: vehicle age of i type at time t)

In our analysis, we estimated the survival function of non-business vehicles, including gasoline, diesel, and EVs, using vehicle stock data from 2017 to 2019. The results showed that the AG variable was statistically significant in all subsamples. Diesel vehicles had a low scrappage rate at young vintages, but their scrappage rate increased abruptly with age, resulting in a shorter average lifespan compared to gasoline vehicles. The AG variable was also statistically significant for EV and FCEV samples, but due to the relatively recent introduction of EVs in Korea, we had insufficient data to estimate their full lifespan accurately. Therefore, we used the average survival rate of gasoline and diesel vehicles to approximate the survival rate of EVs.

| | | Estimated coefficient | Standard error | Z-value |
|---|---|---|---|---|
| All | intercept | 3.417*** | 0.62 | 5.46 |
| | AG | -0.247*** | 0.07 | -3.46 |
| Gasoline | Intercept | 3.589*** | 1.19 | 3.02 |
| | AG | -0.281** | 0.12 | -2.25 |
| Diesel | Intercept | 5.653** | 2.23 | 2.53 |
| | AG | -0.387* | 0.21 | -1.87 |
| EV, FCEV | Intercept | 3.372** | 1.35 | 2.50 |
| | AG | -0.443* | 0.23 | -1.94 |

**Table 2 Estimation result of survival functions**

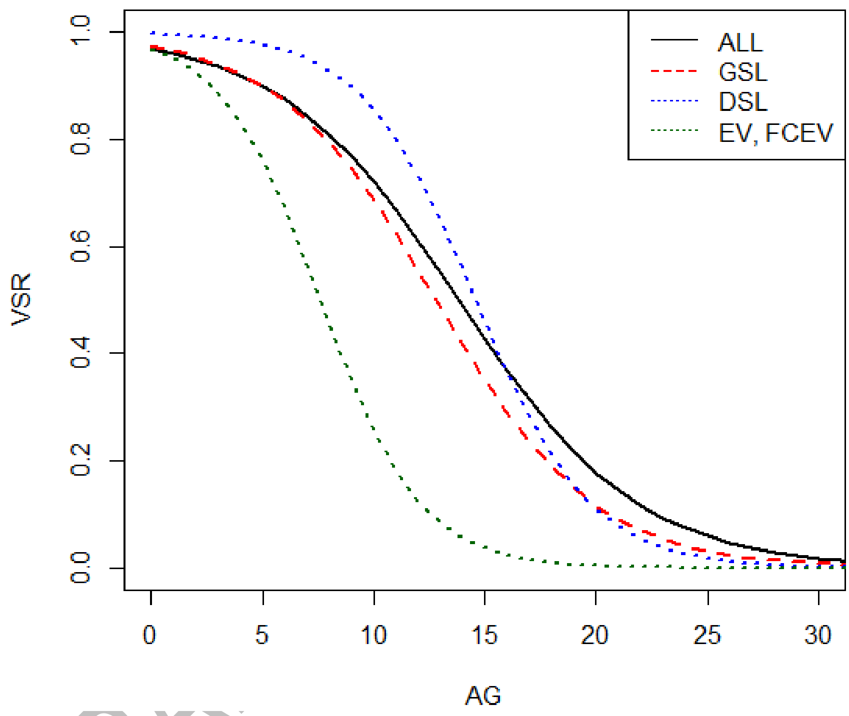


**Figure 3 Survival function by fuel type**

(GSL: gasoline vehicle, DSL: diesel vehicle, EV: electric vehicle, FCEV: fuel-cell electric vehicle)



3.2 Method:

(1) CGE model structure

This paper presents an economic model that combines the traditional top-down CGE model with a new vehicle stock model. While the CGE model is widely used to evaluate the economic impact of reducing GHG emissions, it typically assumes a simplified structure of each industry and does not account for the dynamic accumulation of vehicle stocks. Therefore, we introduce a vehicle stock model to capture the use of fuels of former vehicle stocks.

To construct our CGE model, we use the OECD ENV-Linkage model as a starting point. However, to focus on the Korean context, we develop a single country recursive dynamic model and simplify it by not distinguishing capital vintages. Domestic output production is a Leontief function of value added composite and intermediate inputs. The value-added composite comprises labor and capital-energy composite, which we model using a CES function with sigma from the GTAP 10 database. We represent the energy transition by setting the energy composite as a CES function of electricity and non-electricity with a sigma of 2. To represent the energy structure, we use several electricity and non-electricity energies with CES functions.

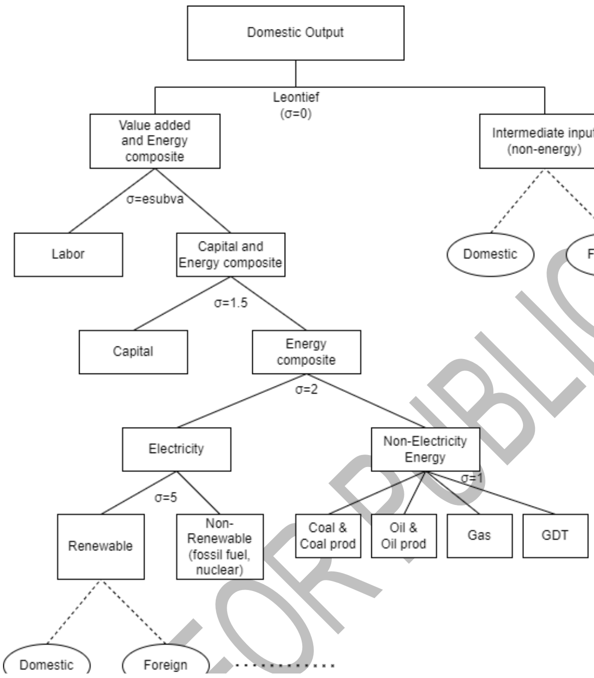


**Figure 5 Production structure**

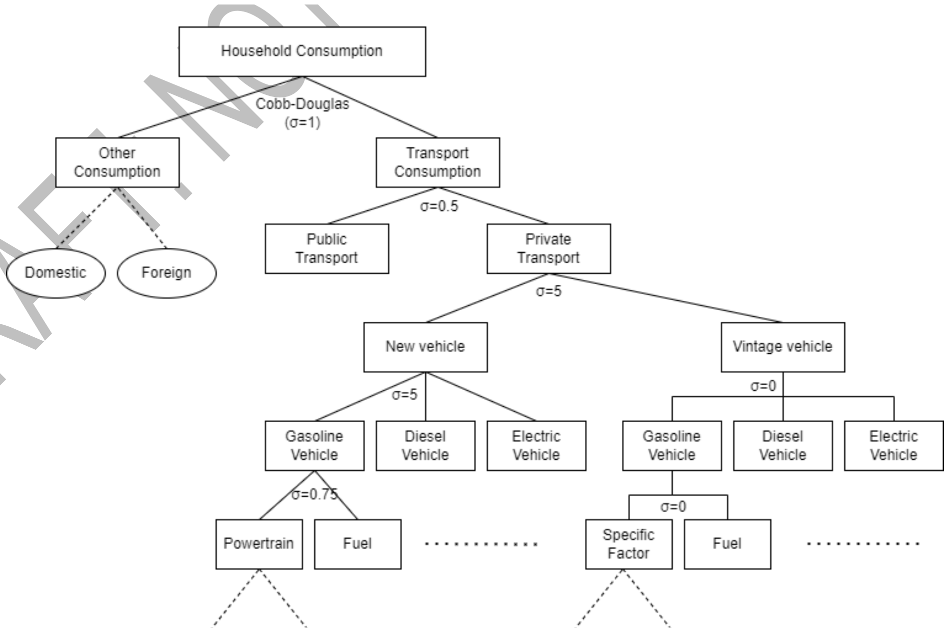


**Figure 4 Constumption structure**

In the domestic consumption section, we pay particular attention to the transport composite, which is a CES composite of public and private transport with low substitution elasticity. We adopt the substitution elasticity value from Litman (2022). The private transport composite is also a CES function of new and old vehicles. We represent the new vehicles as a CES function of vehicles of different fuel types, where each vehicle is a combination of powertrain and fuel. In contrast, the old vehicle is an Leontief combination of vehicles of different fuel types, where each vehicle is also a Leontief composite of specific factor and fuel. This consumption structure is based on Karplus et al. (2013) and the MIT EPPA model to represent the vehicle choice model structure. Since our model focuses on the transportation sector and lacks GHG emissions data from other industries, we only consider CO2 emissions from fuel combustion. While this model does not account for other GHGs, emissions from industrial processes, or LULUCF, CO2 emissions from fuel combustion account for 91% of net GHG emissions and 87% of total GHG emissions in Korea (KOSIS). Therefore, our model provides a good representation of the GHG emission structure in Korea.

(2) Vehicle stock model

To account for vehicle stock dynamics in the CGE model, we classified vehicles into gasoline, diesel, and electric types, and divided them into vintages ranging from new to 25 years or older. At each time period t, the number of vehicles by vehicle type and age follows a dynamic equation specified by the following:

$$\mathrm{Vstock}(k,t,n) = \begin{cases} \dfrac{SR(k,n)}{SR(k,n-1)} \times V\mathrm{stock}(k,t-1,n-1) & if\ n > 1 \\ \dfrac{QC(k,t) \times (1 + PTC(k,t))}{Vprice(k)} & if\ n = 1 \end{cases}$$

(Where, Vstock(k,t,n): number of k type n vintage vehicles in year t, SR(k,n): The probability that a k type vehicle survives to vintage n (car vintage survival rate), QC(k): consumption expenditure for k type vehicle in year t, PTC: consumption tax rate for k type vehicle in year t, Vprice(k): price of k type vehicle)

As seen in the aforementioned equation, the reduction in the old vehicle stock is governed by the survival rate of a given fuel type, while new vehicle purchases are estimated through the CGE model. Additionally, we presume that the average kilometer traveled is impacted by fuel prices and taxes. In particular, we adopted the price elasticity of average kilometer traveled of -0.85, as suggested by Tilov and Weber (2021). The distance traveled variable can be expressed as follows:

$$VKTn(k,t,n) = \mathrm{AK(k,t)} \times Vstock(k,t,n)$$

(Where, VKTn(k,t,n): Total mileage of k type, n vintage vehicles in year t, AK(k,t,n): Average mileage of k type, n vintage vehicle in year t)

Based on the above two equations, the total mileage of the k-type vehicle supplied in year t is as follows;

$$VKT(k,t,n) = sum(n, VKTn(k,t,n))$$

(3) Parameters and assumptions

To determine sectoral substitution elasticities, we relied on data from the GTAP10 database. These elasticities, which vary by industry, are captured by the esubva value. For the transport sector, we drew from relevant literature where possible. Specifically, we adopted the substitution elasticity between public and private transport proposed by Litman (2022), as well as the substitution elasticity between powertrain and fuel suggested by Karplus et al. (2013). Additionally, we calculated the substitution elasticity between new vehicles of different fuel types based on our own analysis of Korean data.

| Type | Name | Elasticity value |
|---|---|---|
| Substitution elasticity | Value added composite and intermediates | 0 |
| | labor and capital-energy composite | 0.2~1.68 (different by industries (data from GTAP 10 DB) |
| | capital and energy | 0.5 |
| | Electricity and non-electricity energy | 1 |
| | Renewable and non-renewable electricity | 3 |
| | Fossil fuel energies | 1 |
| Armington elasticity | Macro elasticity (Domestic and import goods) | 3.8~16.0 (different by industries (data from GTAP 10 DB ) |
| | Micro elasticity (Sources of imports) | 3.8~34.4 (different by industries (data from GTAP 10 DB ) |

**Table 3 Elasticity assumption**

The inclusion of learning rates and net-zero targets in the model is crucial for assessing the long-term impacts of the policy measures. With regards to electric vehicles, the literature provides various estimates of learning rates. BNEF (2019) estimates the learning rate for EVs at 18%, while Tsiropoulos et al. (2018) propose 15% for Li-ion batteries. Hence, we adopt a more conservative estimate of 15% for EV manufacturing in our model. In terms of renewables, Rubin et al. (2015) suggest different learning rates for wind, solar, biomass, and hydro. Since we group all renewables together in our model, we use an average learning rate of 15%.

Furthermore, we assume that Korea follows the global trend in terms of the deployment of EV fleets and that the price of EV manufacturing is affected by the global deployment. IEA (2022) projects a 30-fold increase in the global EV fleet until 2050.

Lastly, we assume a net-zero target for 2050 based on previous literature. To account for $CO_2$ emissions from fuel combustion, we reference the net-zero path of energy systems provided by IEA (2021), IPCC (2019), and US DOS (2021). IEA (2021) suggests a 78.5% reduction rate from energy combustion, assuming that other emissions can be reduced by BECCS or DACCS. The IPCC special report on 1.5℃ (IPCC, 2019) proposes an average reduction of 62.3% with respect to emissions in 2010 (65.1% reduction from emissions in 2019). US DOS (2021) also proposes a net-zero path of 71% reduction in the non-$CO_2$ part. Based on these sources, we assume a net-zero target with a 70% reduction of $CO_2$ emissions from 2019 to 2050 and linearize the emission target to generate a net-zero path.

### 3.3 Policy scenarios

This study analyzes transportation policies proposed in the Korean government plans and examines their potential impact on the country's net-zero emissions target. The baseline scenario, Business-As-Usual (BAU), assumes no carbon price is imposed for the emission of greenhouse gases (GHGs). In contrast, the Net-Zero Path (NZP) scenario imposes a carbon price endogenously to meet the net-zero path, which assumes a 70% reduction of GHGs until 2050.

The NZP_FEff scenario assumes an improvement in fuel efficiency that aligns with the net-zero pathway. Specifically, this scenario incorporates the fuel efficiency improvement proposed in the 2nd Basic Plan for National Transportation and Logistics Development by the Korean government. According to this plan, the fuel efficiency is expected to increase from 24.3 km/l in 2020 to 33.1 km/l in 2030, indicating an average annual improvement of 3.1%. To simulate this scenario, we assume that the fuel efficiency of gasoline and diesel vehicles will continue to improve at this same rate until 2050.

The NZP_EVPS and NZP_EVPS_ICEVT scenarios represent two different approaches to providing subsidies for electric vehicle (EV) purchases. Currently, under the law, subsidies for EV purchases are set to expire in 2024. However, in both scenarios, we assume that subsidies will continue to be provided after 2024, but in a modified form. Specifically, we assume that subsidies will be provided in an amount equal to the cost gap between EVs and diesel vehicles. In our model, the purchase price of an EV is assumed to be 2.8% higher than that of a diesel vehicle, taking into account the subsidy provided to EVs and the tax imposed on internal combustion engine vehicles (ICEVs). We assume that this 2.8% cost gap will be maintained permanently until 2050 to promote the deployment of EVs.

Under the NZP_EVPS scenario, the subsidy is financed by the overall tax structure. In contrast, the NZP_EVPS_ICEVT scenario assumes that the subsidy amount will be imposed as a purchase tax on ICEVs. This would further increase the purchase tax rate for ICEVs and stimulate the purchase of EVs.

The NZP_DVEX and NZP_ICEVB scenarios are aimed at restricting the operation or purchase of ICEVs. The NZP_DVEX scenario assumes a reduction in the survival rate of diesel vehicles, thereby encouraging early exit of these vehicles. To be specific, we assume that the survival rate of diesel vehicles decreases 1.5 times faster with increasing vehicle age, and diesel vehicles older than 15 years are prohibited from operation. Currently, the Korean government is providing subsidies for the early scrappage of old diesel vehicles that do not meet the Euro 4 standard which is similar to our scenario.

On the other hand, the NZP_ICEVB scenario is more stringent, assuming a complete ban on ICEV sales after 2040. This scenario posits that gasoline and diesel vehicles will no longer be available on the market after 2040, with only EVs being sold. However, ICEV stocks purchased before 2040 will still be operational, gradually exiting the market in accordance with their respective survival rates. This scenario aligns with the EU plan, which prohibits the purchase of new ICEVs after 2035(Source). Also, ICEV sales prohibition is considered in Korea but without any explicit deadline (Government of the Republic of Korea, 2022). In light of these developments, we adopt a more conservative approach and assume that the prohibition on ICEV sales will come into effect after 2040.

The NZP_VMTT, NZP_FuelT, and NZP_DmdM scenarios are designed to manage and reduce private transportation demand. The NZP_VMTT scenario proposes the imposition of a new Vehicle Miles Travelled (VMT) tax. VMT tax is widely considered in many countries, including the US and the EU, as a means to tax electric vehicles (EVs). Currently, the US, EU, and Korea do not tax the operation of EVs, as their current transport tax structure is based on fossil fuel consumption. The VMT tax would tax not on fuel consumption but on the distance traveled, thus requiring EVs to pay for transportation tax. The Korean government is actively considering this tax reform, as the deficit of transportation tax revenue deepens (Park et al., 2021; Choi, 2019).

Conversely, the NZP_FuelT scenario proposes to increase the tax rate on fossil fuels consumed by road transport. For both scenarios, we assume that the tax rate (VMT tax per kilometer and additional fuel tax rate) is determined endogenously to ensure sufficient transport tax revenue. We assume that the transport tax revenue ratio, with respect to total government tax revenue, is the minimum requirement for maintaining the transport system.

Lastly, the NZP_DmdM scenario assumes exogenous private vehicle demand management, with a proposed 4.5% decrease in private vehicle demand until 2030 and a 10.5% decrease until 2050, as proposed in the '2030 NDC' and '2050 Carbon Neutrality Scenario.'

Above policy scenarios are summarized in the below Table 4.

| | **Name** | **Description** | **Detailed description** |
|---|---|---|---|
| | BAU | Current policy | |
| | NZP | Net-zero path with carbon pricing | Follows net-zero path with carbon pricing on CO2 emission |
| Fuel efficiency improvement | NZP_FEff | NZP + Fuel efficiency improvement | Fuel efficiency of new vehicle improves 3.1% annually |
| EV purchase subsidy | NZP_EVPS | NZP + EV purchase subsidy | EV subsidy to match EV price with diesel vehicle price |
| | NZP_EVPS_ICEVT | NZP + EV purchase subsidy + ICE purchase tax | EV subsidy from ICE purchase tax |
| ICEV ban or shorten lifespan | NZP_DVEX | NZP + early exit of diesel vehicle | Survival rate of diesel vehicle shortened exogenously |
| | NZP_ICEVB | NZP + ICEV ban | ICEV sales banned after 2040 |
| Private transport demand control | NZP_DmdM | NZP + private vehicle demand management | Private vehicle demand is managed exogenously to reduce VKT |
| | NZP_VMTT | NZP + VMT tax | Fuel tax on end-user price of fossil fuel |
| | NZP_FuelT | NZP + additional fossil fuel tax | VMT tax on all vehicles (including EVs) |

**Table 4 Policy scenarios**

4. Result

4.1 EV deployment and VKT-

(1) New vehicle purchase

Our findings suggest that the implementation of a net-zero target alone would have a limited impact on the deployment of electric vehicles (EVs). In the Business-As-Usual (BAU) scenario, the proportion of EVs among new vehicle purchases by 2050 is estimated to be approximately 45%. In contrast, following the net-zero path is expected to result in a slightly higher proportion of EV purchases at 45.7%, indicating that the introduction of a carbon price would have a minimal effect on EV deployment. Among the policy tools we examined, the EV subsidy policy (NZP_EVPS, NZP_EVPS_ICEVT) was found to have the highest impact on the proportion of EV purchases. In particular, if the EV subsidy is funded by the tax revenue generated from Internal Combustion Engine Vehicles (ICEVs), the deployment of EVs would be further expanded.

Furthermore, our results demonstrate that following the net-zero path would lead to a reduction in the total number of vehicle purchases. In the BAU scenario, new vehicle purchases are projected to reach 3.5 million. However, under the net-zero scenario, new vehicle purchases are expected to decrease to under 3 million, representing a 14-20% reduction compared to the BAU scenario.

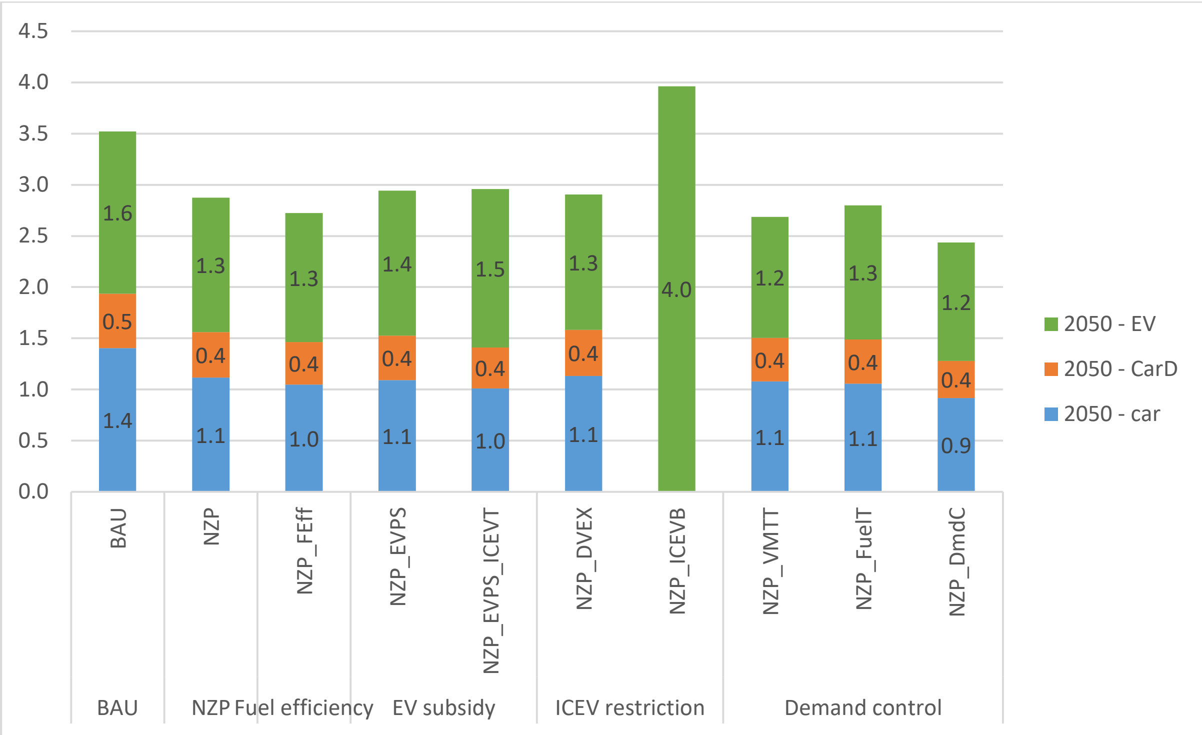


**Figure 6 New vehicle purchase (Unit: millions)**

(2) Vehicle fleet

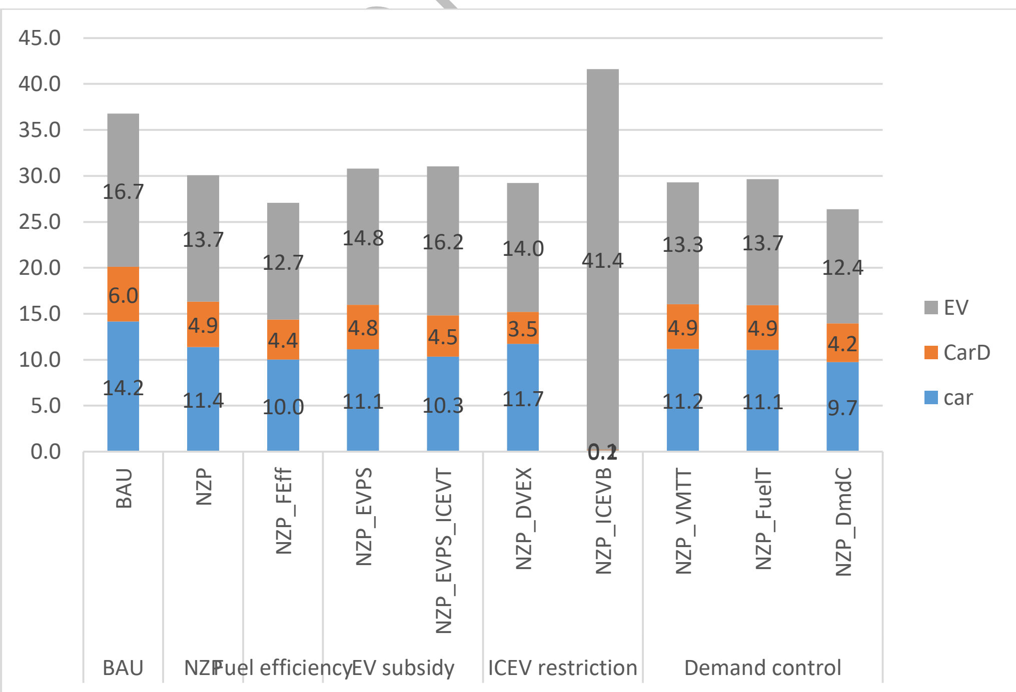


**Figure 7 Total vehicle fleet (Unit: millions)**

(1) VKT

We observe a consistent increase in VKT under the BAU scenario, while the net-zero path shows a peak in VKT around 2040 as the carbon price increases. Furthermore, when other policy tools are implemented together, VKT reaches its peak even faster. Among the various policy tools, we find that fuel efficiency targets and controlling private vehicle demand are the most effective in reducing VKT. These policies decrease VKT by an additional 10% to 13% compared to the NZP scenario.

However, policies that stimulate EV purchases, such as EV subsidies and ICEV bans, may increase VKT as the average kilometer travelled by an EV is larger than that of ICEV. Moreover, the current transport tax system that exempts taxes on EVs exacerbates the VKT increasing problem. Therefore, we suggest that implementing a VMT tax can be an efficient and effective policy. Under the VMT tax scenario (NZP_VMTT), the average kilometer travelled by an EV decreases by 12% more rapidly than the current tax system, ultimately leading to a 5% decrease in VKT compared to NZP scenario.

### 4.2 Economic results: GDP, total labor, sectoral output

(1) Macroeconomic effects

TBA

(2) Carbon price

TBA

### 4.3 Environmental effect

## 5. TBA

## 6. Discussion

TBA

## 7. Conclusion

TBA