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Effect of Hydrogen Production Mix on Hydrogen Fuel Cell Vehicle Adoption and its Environmental Impact

수소 생산믹스를 고려한 수소차의 확산과
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Abstract

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With global climate change emerging as a growing problem by the day, transitioning from the existing era of internal combustion engine vehicles (ICEVs) to the era of alternative fuel vehicles (AFVs) is getting closer. Among AFVs, hydrogen fuel cell vehicles (HFCVs), along with electric vehicles (EVs), are considered to be the next generation of vehicles that will change the state of the future vehicle market, due to their eco-friendliness. However, to establish the eco-friendliness of AFVs, a process of evaluating the environmental aspects of the fuel production process has to be preceded. In this respect, this study attempts to predict the future vehicle market based on consumers preferences considering the fuel production mix of EVs and HFCVs, in order to analyze the environmental impact from diffusion of HFCVs. This study analyzed consumers preferences using the mixed logit model, and the empirical analysis shows that South

Korean consumers prefer EVs operated by renewable energy-oriented generation mix the most followed by EVs operated by current generation mix. In terms of HFCVs, there was no difference between consumers' preference toward HFCVs operated by the hydrogen produced mainly from steam methane reforming (SMR) process and HFCVs operated by the hydrogen produced mainly from electrolysis process. From the estimation results of the choice experiment, this study conducted scenario analysis to expect the future GHG emissions rate from HFCVs by different hydrogen production mix in 2030. About twice the difference in environmental impact was shown as a result of the diffusion of HFCVs according to the two different mixes of hydrogen production.

Keywords: Alternative fuel vehicles, Well-to-wheel analysis, Greenhouse gas emission, Discrete choice experiment, Mixed logit model, Environmental assessment

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Contents

List of Tables

List of Figures

Chapter 1. Introduction

Climate change issues related to global warming are becoming a more prominent problem nowadays. Many countries are striving to gradually reduce greenhouse gas (GHG) emissions in order to cope with climate change. One of the representative measures to bolster the effort to reduce GHG emissions is to increase the production of alternative fuel vehicles (AFVs), while reducing the production of internal combustion engine vehicles (ICEVs). Alternative fuel is a type of motor energy, other than conventional fuels, that consists of electricity, liquefied petroleum gas (LPG), natural gas, mixtures of alcohols with other fuels, hydrogen, biofuels, and other non-fossil fuel components.[1] The main AFVs that we can encounter on the roads are electric vehicles (EVs) and hydrogen fuel cell vehicles (HFCVs), which will be the main objects of consideration in this study. The United Kingdom plans to prohibit the sale of gasoline, diesel, and hybrid vehicles by 2035, while Germany and France have passed resolutions banning the sale of fossil fuel vehicles by 2030 and 2040, respectively. The permissible level of carbon dioxide emitted from vehicles will also be reduced to 62g/km by 2023 in European Union (EU). Due to these strict environmental regulations and inspection procedures, production of ICEVs is expected to decrease sooner than the dates when the aforementioned countries declared a ban on fossil fuel vehicles. In South Korea, there is no official announcement yet on the withdrawal of ICEVs, but the public sector plans to

[1] Eurostat (2020) statistics explained

purchase more than 80 percent of new vehicles as AFVs by 2021 and plans to gradually increase the ratio of eco-friendly vehicles in the sector to 90 percent by 2030.

Unfortunately, the world is facing the biggest pandemic in decades, COVID-19, which has led to a global economic downturn. Since the deadly virus has completely changed our traditional lifestyle in every country, it has stimulated the notion that the world, as a united entity, should immediately take action on global issues, such as global warming. To cope with not only the economic downturn but also global warming, companies have switched their focus to the hydrogen production industry. Hydrogen, extracted by applying a certain amount of heat and pressure to water, has great potential, such as its abundance as a resource, its absence of GHG emissions, its stability of supply from international affairs, its high fuel efficiency, and its reduction of reliance on traditional fuels. In July 2020, the EU Commission announced its hydrogen strategy to promote the hydrogen economy to 140 billion € (70 times larger than the current 2 billion €) within 10 years. South Korea announced its “Hydrogen Economy Roadmap” in 2019 in order to foster its hydrogen industry. The South Korean government also emphasized the importance of the hydrogen economy by introducing it as part of the Green New Deal policy, which was recently put forward to overcome the economic downturn caused by the COVID-19 pandemic. Prior to the outbreak of COVID-19, Japan adopted a “Basic Hydrogen Strategy” in 2017, in order to develop a hydrogen economy for self-reliant energy supply, suggesting the overall direction the hydrogen economy might take by 2050. Moreover, in resource-rich countries like Australia, a hydrogen road map was already established in 2018 to promote the world's largest hydrogen production and export strategy.

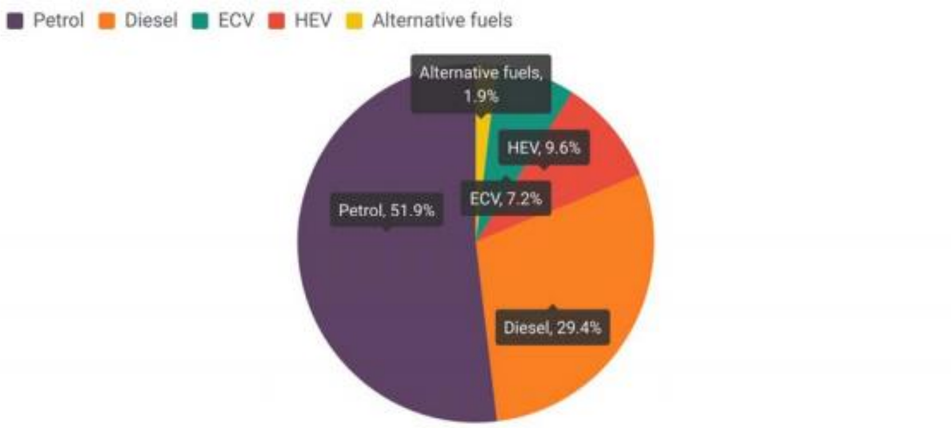
Hydrogen fuel, which is considered an important resource that can solve both issues of climate change and economic recession at the same time, is drawing more and more attention, but it is a subject that needs to be fully scrutinized. The main reason such scrutiny is called for is that in order for hydrogen to be evaluated as a complete eco-friendly resource, GHG generation should be avoided not only during the fuel-use process (driving) but also during the production phase of hydrogen. Hydrogen is called an energy carrier because it is a resource that is extracted from primary and renewable energy rather than from mining, as is required by fossil fuels. Therefore, hydrogen's environmental benefits depend on what energy source it is produced from. This study considers the distinct characteristics of hydrogen production and the environmental impact that HFCVs will have, depending on the process of hydrogen production used. This study also assesses environmental effect of the hydrogen production mix against an increased market penetration rate of HFCVs is increased. Based on this assessment, this study provides policy implications on what kind of production mix is reasonable for HFCVs distribution in terms of a well-to-wheel (WTW) analysis.

This study consist of the five chapters as follows. First, in Chapter 1, we identified which measures that each country has in place with AFVs in relation to the global warming. Next, in Chapter 2 current status of AFVs with regards of policies from various countries is introduced. Then it comprehensively organizes studies on consumers' choice of AFVs and studies on analyzing the environmental impact of vehicles using various types of fuels. Chapter 3 explains the research methodology that is intended to be used in this study with specification of model used in this study. Chapter 4 briefly describes the data required for analysis and the estimation results of this study. Then, various simulations are to be conducted from several scenarios. In Chapter 5, this study suggests implications that were derived and offers suggestions on research that will supplement our findings in the future.

Chapter 2. Literature Review

2.1 Current Status and Policies Regarding AFVs

Currently, many countries are encouraging an increased production of vehicles using battery or alternatively powered engines. According to the Clean Mobility Package announced by the European Commission in 2017, a plan to reduce 60 percent of GHG emissions by 2050, with respect to 1990 levels, will be carried out through a transition to low- and zero-emission vehicles. Moreover, regarding recent bounce-back plans for the auto industry in the EU due to the COVID-19 pandemic, the European Commission proposed about €20 billion in purchasing facility over the next two years for eco-friendly vehicles. This is in line with EU standards, along with a €60 clean automotive fund, which is being rolled out to accelerate investment in zero-emission vehicles.[2]



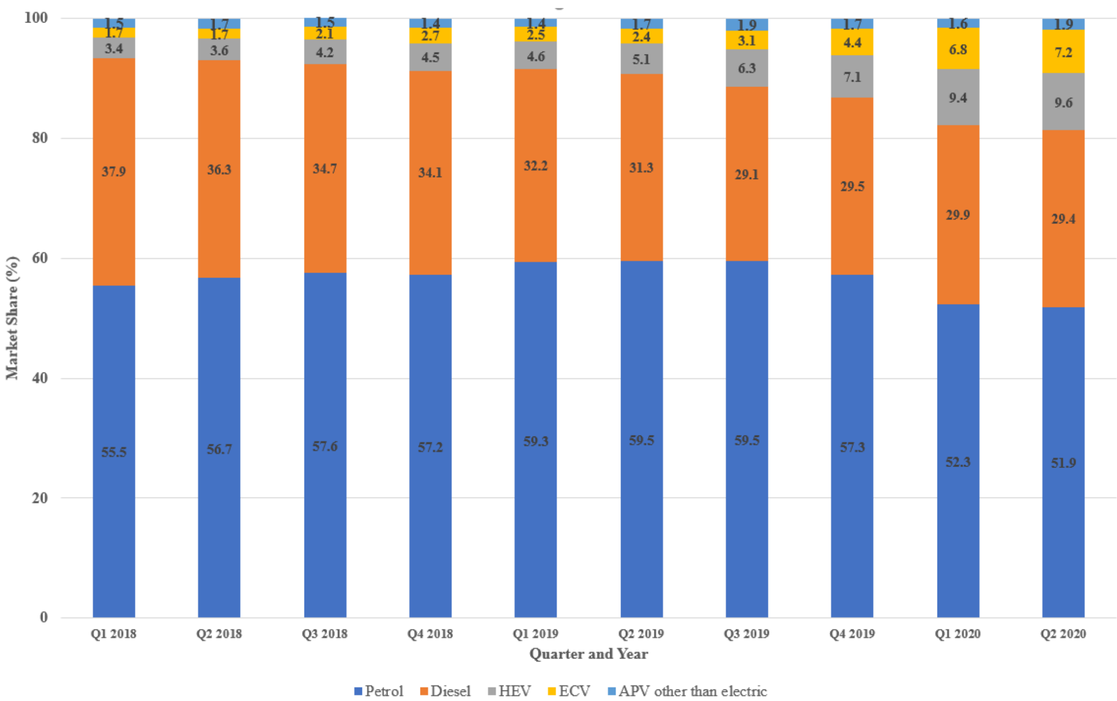
[2] https://www.assetfinanceinternational.com/index.php/auto-finance/auto-emea/auto-emea-articles/19397-european-commission-unveils-80-billion-bounce-back-plans-for-auto-industry

Figure 1. New passenger car registrations by fuel type in the EU (2nd quarter of 2020)

Source: ACEA (European Automobile Manufacturers Association)

In Europe, although the proportion of gasoline (petrol) and diesel cars is still high, as shown in Figure 1, the share of EVs and hybrid electric vehicles (HEVs) is gradually increasing, as shown in Figure 2. However, the market share of AFVs other than EVs and HEVs is still at a very low level. This is due to the fact that the commercialization period of HFCVs is shorter than that of EVs, and the fact that only Toyota, Honda, and Hyundai are the current manufacturers of HFCVs, which results in a dearth of such vehicles in the European market. Recently, the European Green Deal was instituted to switch the EU nations from a high-carbon economy to low-carbon economy by improving well-being through cleaner air and a “circular economy”, with the main policy initiative being the attainment of net-zero global warming emissions by 2050. Under the European Green Deal, hydrogen will play a key role for meeting the objectives of the project. Therefore, it is likely that the utilization of hydrogen fuel in the transportation sector in the EU will increase in the near future.

China and the United States (U.S.), which have the first and second largest EV markets in the world, account for 52.9 percent and 14.3 percent of the total number of global EV sales, respectively. China and the U.S. are also implementing various policies to promote the distribution of AFVs. The Chinese government declared its intention at the U.N. General Assembly 2020 to achieve carbon neutrality by 2060, which is the state of no longer increasing GHG emissions. In particular, when it comes to environmental policies related to the transportation sector, the Chinese government introduced NEV Credit, which imposes a mandatory ratio production of high-fueled internal combustion engines and eco-friendly vehicles on Chinese automobile manufacturers. In the US, there are two main standards related to AFVs, which are federal fleet GHG emissions standards and Corporate Average Fuel Economy (CAFE) standards, along with the state policies regarding incentives to AFVs and mandating approximately 35 percent of vehicle sales for AFVs in 10 states, including California (Jenn et al., 2019). Fleet GHG emission standards regulate GHG emissions by setting different criteria, depending on the size of vehicles for manufacturers, whereas CAFE applies to the average efficiency of all the cars that a manufacturer sells in a year.[3]



3 https://theicct.org/cards/stack/us-passenger-vehicle-cafe-and-ghg-regulations-basics#2

Figure 2. Trend of new passenger car registrations by fuel type in the EU

Source: Reprinted from ACEA Report on AFV Registration

South Korea is also one of the leading countries that makes great efforts to promote AFVs, though the current status of the AFV market in South Korea is still anemic. As of the first half of 2020, a total number of about 680,000 eco-friendly vehicles (hybrid cars, EVs, HFCVs) were registered in South Korea. Of that total, 500,000 are hybrid cars, followed by 100,000 EVs, and about 7,000 HFCVs. The proportion of newly registered eco-friendly vehicles per year keeps increasing, however, and has exceeded 1 percent since 2016 and risen to 2.87 percent as of the first half of 2020. The summarized status of South Korean eco-friendly vehicles, or AFVs, is presented in Table 1.

Table 1. Status of AFV market in South Korea

Period	2014	2015	2016	2017	2018	2019	2020
Total vehicles	20,117,955	20,989,885	21,803,351	22,528295	23,202,555	23,677,366	24,023,083
Total AFV	140,297	180,361	244,158	339,134	461,733	601,048	689,495
Hybrid	137,522	174,620	233,216	313,856	405,084	506,047	570,506
EV	2,755	5,712	10,855	25,108	55,756	89,918	111,307
HFCV		29	87	170	893	5,083	7,682
Share of AFV	0.70%	0.86%	1.12%	1.51%	1.99%	2.54%	2.87%

Source: Reprinted from Korea Automobile Manufacturers Association

According to the Strategy for the Development of the Future Automotive Industry, declared by the South Korean government in 2019, innovative changes in the automobile industry are underway, due to the 4th Industrial Revolution and strengthened environmental regulations. Therefore, the South Korean government expects to popularize eco-friendly vehicles by increasing sales of EVs and HFCVs from 2.6 percent in 2019 to 33.3 percent by 2030. In order to encourage the conversion to eco-friendly vehicles, there are several government incentives for consumers who purchase AFVs. For instance, the government provides about 36 million won for HFVCs and 19 million won for EVs, whereas subsidies for hybrid vehicles have been suspended since 2019. Furthermore, there are also monetary benefits, such as vehicle acquisition tax reduction, discounts on public parking fees, and exemption of tolls, to consumers who buy AFVs. In addition to the monetary incentives, the Ministry of Land, Infrastructure and Transport has also lobbied for a revision of the Act to expand parking areas exclusive for EVs and HFCVs in off-road parking lots.

2.2 Review about Consumers' Preferences toward AFVs

In order to examine the environmental effects of increasing in HFCVs, finding out how the diffusion of HFCVs will occur is necessary. The distribution of HFCVs depends on how the number of other fuel types of vehicles, such as gasoline, diesel, and EVs, will change in the future. Therefore, analyzing consumers' vehicle purchasing choices is important to predict the future market share of HFCVs. There have been many studies on the distribution of AFVs based on consumers' choices. Moon et al. (2018) analyzed consumer preferences for gasoline, diesel, hybrid, and electric vehicles by setting fuel cost, vehicle price, fuel type, vehicle type, and charging station accessibility as core attributes. Furthermore, based on the distribution scenario, the study predicted how demand for electricity would change, based on an analysis of consumers' EV charging patterns. In the study, the prediction of electricity demand was calculated by taking into account how fuel cost, vehicle purchasing prices, and accessibility of charging stations would change in the near future. According to the study, the market share of EVs in South Korea was expected to increase by about 6 percent when technological improvements were considered. In addition, EV drivers were found to be more likely to charge during the evening when they used private EV charging facilities, whereas they preferred to charge during the daytime when they used public EV charging facilities, which led to an increased demand for electricity from 194 to 447 MWh. Although this study did not further analyze the GHG emissions of AFVs, it is believed that this study will help to accurately predict future alternative fuel usage in terms of predicting the demand by reflecting consumers' charging behaviors.

Hoen & Koetse (2014) conducted a choice experiment to analyze consumers' preferences on AFVs in the Netherlands. Because the author stated that attributes such as fueling time and availability of fuel should be included in the attributes for a choice experiment, as they affect AFV preferences substantially, the experiment for this study was designed by including purchase price, monthly costs, driving range, recharging and refueling time, additional detour time, policy measures, and number of models as attributes for vehicle choices. The research found that consumers' preferences for AFVs are likely to increase when the driving range and refueling times are improved, while the preferences for AFVs are lower than those for the ICEVs, due to the lack of infrastructures and technological hindrances.

There is also another study which conducted a choice experiment to examine the eco-friendly vehicles preferences of Korean drivers and non-drivers (Byun et al., 2016). Byun et al. (2016) included gasoline, diesel, electric, and hydrogen fuel cell for the fuel types of vehicles. They also included CO2 emissions, number of charging stations, fuel refilling time, car maintenance cost and car purchase price for the attributes of the choice experiment design (Byun et al., 2016). According to (Byun et al., 2016), Korean drivers prefer less CO2 emissions, more charging facilities, shorter fuel refilling time, and lower maintenance cost and purchase price of vehicles in general. The study also found that the drivers are willing to pay about 30,233 additional KRW for a 1% decrease in CO2 emissions for a vehicle, which implies that recent drivers consider about the environmental performance of the vehicles. Moreover, the results of the study show that the respondents are willing to pay about 7.9 million KRW and 11.17 million KRW for EV and HFCV, respectively when they change their vehicle types from the gasoline, which also implies that Korean consumers prefer the eco-friendly vehicles.

Recently, many studies have been conducted consumers preferences toward AFVs mainly focusing on the diffusion of HFCVs. Khan et al. (2020) used mixed logit model to elicit 500 Japanese potential car buyers' preferences toward AFVs to figure out the key attributes of vehicles in order to promote the adoption rate of the HFCVs. According to the study, consumers prefer HFCVs when the purchase price and recharging time of the vehicles get lower. Moreover, the authors added government incentives regarding HFCVs such as free public parking, tax discount, toll exemption on expressways and free public transport on weekends to analyze the key factors of policy incentives for the diffusion of HFCVs (Khan et al., 2020). Average MWTP for free public parking, toll exemption, and free public transport were 1,476,635, 517,134, and 862,150 JPY, respectively. The results indicate that the non-financial incentives like free public parking and free public transports for on weekends can foster the diffusion of HFCVs in Japan. Li et al. (2020) estimated Chinese consumers' WTP for attributes of HFCVs by using a choice experiment in order to conduct economic analysis for HFCVs. Li et al. (2020) included purchase price, driving range, refueling time, fuel cost, and emissions reduction, and refueling accessibility as the attributes of vehicles. The analysis of the study shows that Chinese consumers are willing to pay about 49,091 RMB for improving the 200 km of driving range of HFCVs, 12,727 RMB for reducing the 5 minutes of refueling time of HFCVs, 3818 RMB for decreasing RMB 0.5/km of fuel cost of HFCVs, and 12,909 RMB for expanding about 20% of HFCVs refueling accessibility. For the GHG emissions, which is mainly related to the environmental performance of HFCVs, Chinese consumers are willing to pay about 47,818 RMB for reducing 20% of emission rate of HFCVs, which implies that Chinese consumers also consider the environmental factors when purchasing a new vehicle. In line with the global trend that HFCVs are gaining much attention as eco-friendly vehicles along with EVs, many researchers seem to be conducing choice experiments to examine the adoption factors of HFCVs.

2.3 Review about GHG Emissions of AFVs

In addition to projecting the distribution of AFVs, it is necessary to see how GHG emissions will change when the number of AFVs increases. There are also several studies that projected the amount of GHG emissions by the fuel types of vehicles, based on a life cycle assessment perspective, when the number of AFVs was increased in a simulated model of the future. Woo et al. (2017) estimated the WTW GHG emissions of ICEVs and EVs based on power generation mixes in 20 countries. The study was conducted in light of the fact that driving electric vehicles in countries that do not implement an eco-friendly power generation mix may not have a positive effect on the environment. Similar to the author's expectations, some countries even show more GHG emissions from EVs than ICEVs, due to a high proportion of fossil fuel generation. This implies that the promotion of electric vehicles should once again be considered in countries with a high proportion of fossil fuel generation. Another study analyzed GHG emissions of AFVs in light of fuel mix changes in South Korea. Because the electricity generation mix is considerably affected by the government's decisions on energy policies, the study examined GHG emissions of EVs based on South Korea's 8th Basic Plan for Supply and Demand of Electric Power (Kim et al., 2020). Furthermore, this study also estimated GHG emissions of HFCVs using electrolysis by considering the power mix plan of South Korea in 2030.

The estimation results showed that EVs and HFCVs are expected to emit 121.99 gCO_2-e/km and 64.07 gCO_2-e/km in 2030, respectively. Choi et al. (2020) also conducted an assessment on the GHG of ICEVs, hybrid vehicles, plug-in hybrid vehicles, EVs, and HFCVs in terms of WTW perspective. Based on two electric power generation mix policies and three hydrogen production policies in South Korea, the study predicted the vehicle markets in 2030 and calculated the WTW GHG using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (Greet) model after assuming how the fuel economy level of each fuel type would be improved (Choi et al., 2020). According to the results, WTW GHG for each fuel type was 161, 110, 97, 86 and 91 gCO_2-e/km, respectively, which was calculated by converting three other greenhouse gases into CO_2 values ($1CO_2=25CH_4=298N_2O$). However, this study assumed the number of future vehicles based on the government's policies, which therefore lacked insight into consumer preferences in vehicle purchasing decisions.

2.4 Contribution of this Study

Recently, many studies have added environmental aspects to the list of attributes when analyzing consumer choice in purchasing vehicles, which allows researchers like us to see a more realistic choice probability for purchasing AFVs. Studies that considered environmental aspects on consumers' vehicle purchasing choices are as follows. Ito et al. (2013) estimated potential infrastructure investments for AFVs by applying stated preference methods to consumers in the Japanese vehicle market. They designed the experiment by setting manufacturer, cruising range, charging time, carbon dioxide reduction rate, fuel availability, annual fuel cost, and purchasing price as main attributes for gasoline vehicles (GVs), HEVs, EVs, and fuel cell vehicles (FCVs). There is also a study that included biofuel vehicles, natural gas vehicles, EVs, HFCVs, hybrid cars, and plug-in hybrid vehicles in the analysis categories of AFVs distribution. The authors used a mixed logit model to determine the probability of consumers' purchasing decisions between AFVs and conventional ICEVs while using purchasing price, fuel cost, carbon dioxide emissions, maximum drivable range, fuel charging time, and government incentives as the core attributes of vehicles (Hackbarth & Madlener, 2013). Another study compared and analyzed the preference for AFVs (EVs & plug-in hybrid vehicles) of U.S. and Japanese consumers through discrete choice experiments using conditional logit models. The study found that U.S. consumers consider reduced fuel efficiency and accessibility of charging stations to be more important than Japanese consumers, which led to the purchasing probability of AFVs from U.S. consumers at 13% and Japanese consumers at 25 percent (Tanaka et al., 2014).

However, few studies have taken into account the mix of energy sources when examining the distribution of AFVs. Choi et al. (2018) analyzed how consumer adoption behavior of EVs differed based on the changes of a power generation mix of electricity in South Korea, which is directly linked to the environmental impact of EVs. The authors set four different levels of attributes for the operation method of electric vehicles, and adjusted the share of each power source. The study found that South Korean consumers have a greater preference for EVs using fossil fuels rather than nuclear power. This implies that South Korean consumers consider the risk of using nuclear power to be more severe than the risk of contributing to climate change. According to the estimation result of the study, the consumers are willing to pay about 7700 USD more for EVs using a renewable energy-oriented mix of electricity than the current South Korean electricity generation mix, while the renewable energy-oriented generation mix could push the EVs market share up to 10 percent with a reduction of GHG emissions up to 5 percent by 2026.

This study seeks to supplement the achievements of the preceding studies by focusing on what follows. Many previous studies forecast the future state of AFVs by focusing only on the distribution of AFVs. As environmental issues become more important and have a greater impact on the purchasing decisions of consumers, a comprehensive examination of consumers' choices regarding energy production mixes would offer meaningful insights. Given this, our study is the first to consider the impact that a hydrogen production mix of fuel has on consumers' vehicle purchasing decisions. Therefore, this study pairs consumers' choice probability with various kinds of hydrogen production mixes in HFCVs, along with power generation mixes in EVs.

Hydrogen fuel cannot be regarded as a completely eco-friendly fuel resource because carbon dioxide and other kinds of GHGs are emitted during hydrogen production processes when fossil fuels such as liquefied natural gas (LNG) or coals are used in the steam methane reforming (SMR) process. Moreover, in the case of hydrogen derived from electrolysis, if the electric power used to perform this process comes from sources other than renewable energy or nuclear power, then the resulting hydrogen also cannot be considered as a completely eco-friendly resource. Although hydrogen derived from electrolysis using renewable energy is certainly eco-friendly, there is a limit to increasing hydrogen derivation through this process unless the caliber of renewable energy generation technology is drastically improved in order to reduce the unit production cost. In South Korea, for instance, it is necessary to use byproduct hydrogen, which is produced during the petroleum refining process within the petrochemical industry. Since byproduct hydrogen is already produced in the process required by existing industries, this hydrogen fuel has the highest economic feasibility with no additional GHG, which has already been accounted for in the petroleum refining processes. Therefore, as the demand for hydrogen fuel increases, it is practical to cover the surplus of hydrogen demand that cannot be covered by the byproduct hydrogen derived from using SMR or electrolysis methods.

In this context, this study seeks to determine how the well-to-wheel environment of HFCVs brings about change, depending on how a mix of hydrogen production methods are set up when AFVs are distributed in the near future. In this study, we want to examine how consumers' choices vary, depending on the environmental aspects of fuel types for EVs and HFCVs when consumers purchase new vehicles. Therefore, to represent the environmental performance of AFVs, we set the different levels of the power generation mix and the hydrogen production mix in order to examine whether eco-friendliness of AFVs can affect consumer adoption behavior of AFVs. A choice experiment that reflects the heterogeneity of consumers will show how the market share (which is currently dominated by conventional ICEVs) of EVs and HFCVs will change. Economic feasibility and environmental effects may vary, depending on the hydrogen production method. For instance, hydrogen derived from electrolysis has a higher value on environmental performance, while SMR hydrogen has a higher value on economic feasibility. Therefore, this study analyzes how the trade-off between these two methods of production affects the amount of GHGs emitted from HFCVs. We expect that the analysis we conduct in this study will help support which hydrogen production lines governments should focus on when promoting a hydrogen economy. Furthermore, results of the study might help many countries boost their hydrogen fuel industries in consideration of environmental aspects once a hydrogen fuel era takes hold.

Chapter 3. Methodology

3.1 Research Framework

The research question we ask in this study is how the environmental performance of HFCVs will vary, depending on a hydrogen production mix, when the market share of HFCVs increases. To examine this research question, this study aims to forecast the number of registered HFCVs in South Korea in 2030. Based on the predicted number of HFCVs, this study will eventually estimate the GHG emissions of HFCVs by reflecting each hydrogen production method's GHG emission levels. To meet the objective, a discrete choice experiment will be conducted in advance, to collect the data about consumers' choices on their vehicle purchasing decision. Next, from the acquired data conducted by the discrete choice experiment, analysis of data will be processed. In the analysis stage, in order to capture consumers' preferences on various types of vehicles and their attributes, a mixed logit model, which is a type of discrete choice model, will be used to estimate the coefficients of the attributes of each vehicle type. Based on the estimation, a prediction for the market share of HFCVs will be made, along with a prediction of other fuel types of vehicles. Furthermore, by adding potential attributes of alternatives, the future state of HFCVs will be simulated. Lastly, from the simulated results, this study will forecast the amount of hydrogen usage required by the transportation sector in 2030, and will calculate its GHG emissions according to various hydrogen production methods. A comprehensive schema of the research framework is depicted in Figure 3.

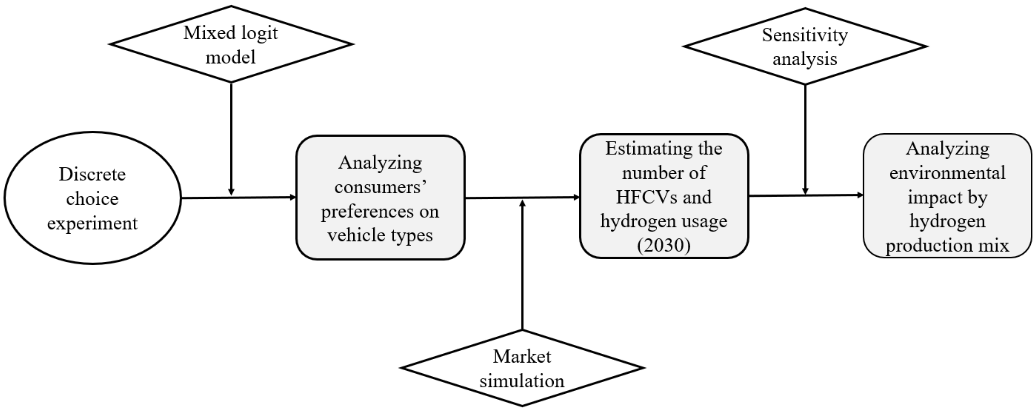


Figure 3. Schema of the research framework

3.2 Discrete Choice Experiment

3.2.1 Stated Preference Approach

The main methodology of this study is a discrete choice experiment based on the collected consumers' stated preference data. The stated preference method is a marketing research technique used to elicit preferences of individuals by asking respondents to rank, judge, or choose attributes or alternatives from hypothetical choice situations (Adamowicz et al., 1994). In contrast, the revealed preference approach measures consumers' preferences on certain products or attributes by observing consumers' purchasing behavior, such as is done in the travel cost method or the hedonic price method (Samuelson, 1948).

Both approaches, which are based on random utility theory, deal with consumers' preferences on goods that are traded on the market, such as products and services (Alpizar, 2001). Along with traditional approaches that use real behavior-based revealed preference data, the stated preference method has been widely used in environmental, health, and resource economics since the mid-1990s (Louviere et al., 2010). Although the revealed preference method has strength in using data based on actual behaviors of consumers, there are several advantages of the stated preference method over the revealed preference method in terms of deriving individuals' attitudes about goods. The stated preference method can cover the variables that a researcher has interest in because it can estimate the parameters of the variables that reflect the trade-off ratios (Kroes & Sheldon, 1988). Furthermore, the stated preference method can examine consumers' preferences for goods or services that have not yet existed on the market (Kroes & Sheldon, 1988). Due to these relative advantages of the stated preference method, this study attempts to use the stated preference approach to examine various preferences of consumers toward vehicle types, especially for HFCVs, which have not yet been distributed much in the market.

3.2.2 Selection of the Methodology

The contingent valuation method (CVM) and the discrete choice experiment are the most widely used stated preference techniques to elicit consumers' preferences for alternatives (Carson and Louviere, 2011). The CVM is also a survey-based monetary valuation method that usually derives respondents' willingness to pay for non-market resources (van denBerg et al., 2005). Although the CVM can be applied to a wide range of resources, it cannot measure the values of multiple alternatives and attributes that the researcher wants to examine (Wang et al, 2006; Jin et al, 2018). Hence, the CVM is more appropriate for use in assessing the potential effects of a policy change when it is otherwise difficult to measure with market-based valuation methods.

On the contrary, the choice experiment uses attributes and levels of choice situations that the researcher is interested in and that allow researchers to predict the market share of goods that are being considered (Boxall et al., 1996). In the choice experiment, respondents are asked to choose the best or multiple alternatives they most prefer between different bundles of goods (Hanley et al., 1998). By using the choice experiment, which is different from the single specific scenario used in the CVM, researchers can value the attributes from their scenario (Adamowicz et al., 1998). Furthermore, the choice experiment is more convenient to use than the CVM in calculating the trade-offs between attributes. In this study, where the main objective is to estimate the potential GHG emissions from HFCVs by forecasting the future vehicle market state, the choice experiment method is therefore used to measure and examine different consumers' preferences over various vehicle types.

Because the market for HFCVs has not been vitalized yet, it is appropriate to use a choice experiment method. In order to forecast the demand for HFCVs, the discrete choice experiment elicits respondents to choose a vehicle type they most prefer through a hypothetical market that resembles a consumer's choice situation in a real market. The choice experiment takes the form of a survey protocol to create a hypothetical market situation and derive consumers' potentials (Dachary-Bernard and Rambonilaza, 2012). A detailed explanation for the design of the survey and the construction of the experiment will be described later.

There are also various econometric methodologies that can be used to analyze the results of the discrete choice experiment. Among the various methodologies, logit models are widely used econometric methodologies in experiments related to consumers' choice problems. However, as standard logit models are limited in reflecting consumers' heterogeneous preferences on each attribute of alternatives, this study uses a mixed logit model, which can reflect various heterogeneities of respondents in measuring consumers' preferences on different attributes of each vehicle type.

3.2.3 Survey Design

Prior to the empirical analysis of consumers' preferences on the vehicles, this study conducted a discrete choice experiment to acquire stated preference data of respondents. As mentioned earlier, the choice experiment must be designed as respondents can believe the hypothetical experiment condition is similar to an actual choice and purchase situation. To create the hypothetical condition, the experiment is conducted in the form of a survey, in which respondents are encouraged to choose their most preferred type of vehicle after being presented with several alternatives of vehicles with various attributes.

In this study, we first identified the attributes that could affect consumers' choices in purchasing a 2000cc midsize vehicle. Fuel types of vehicles were divided into internal combustion engines consisting of gasoline and diesel fuels, electric energy, and hydrogen fuel. For the ICEV models, which use internal combustion engines, we combined both gasoline and diesel into one fuel category, as there are not many available 2000cc midsize vehicles using diesel in the current South Korean vehicle market. Electric energy, which is a main source of fuel for EVs, was divided by its generation mix types, which maintain a current status, significantly reducing the share of nuclear power compared to the present, and significantly increasing the share of renewable energy compared to the present. Hydrogen fuel, a main source of fuel for HCFVs, was also divided by its production mix types. Because hydrogen fuel in South Korea will be consumed as byproduct hydrogen as the priority, the hydrogen production mix in the attribute was assumed to be derived from this type of production method. The choice of hydrogen production mix is composed of an SMR-oriented production mix and an electrolysis-oriented production mix that uses renewable energy. In the case of fueling and charging times, the levels are composed of 5, 20, 40 and 60 minutes. Fuel costs per kilometer are based on fuel prices currently traded in South Korea, but have been slightly corrected to make it easier for respondents to recognize differences between the attribute levels. In addition, in order to make the respondents feel as if the setup were realistic, a translation of the unit fuel price to the monthly fuel cost reflecting the average mileage of 1,300killometers per month in South Korea was listed. Charging and accessibility of fuel indicated a percentage of gas and charging stations available for the fuel type compared to the total number of gas stations currently available. Maximum drivable ranges of vehicles that could be driven on a single full charge were set at 400 kilometers, 600 kilometers, 800 kilometers, and 1,000 kilometers. Lastly, prices for purchasing a vehicle were set by reflecting the range of prices for a 2000cc midsize car currently traded in the South Korean market. Table 2 presents the overview of the attributes and their levels used for the choice experiment in this study.

Table 2. List of attributes and attribute levels

Attribute	Description of attribute and levels	
Fuel type with generation and production mix	Description	Fuel type of vehicle and its energy generation and production mix (EV and HCFV only)
	Level (6)	1. ICEV (gasoline and diesel) 2. EV (current status) 3. EV (reduction in nuclear power) 4. EV (expansion in renewable energy) 5. HFCV (SMR-oriented) 6. HFCV (electrolysis-oriented)
Fuel charging time	Description	Time taken for full charging of fuel
	Level (4)	1. 5minutes 2. 20minutes 3. 40minutes 4. 60minutes
Fuel price (per/km and	Description	Price of fuel per 1km (assuming an average monthly driving distance is 1300km)

monthly cost)	Level (4)	1. 25 KRW/km (32,500 KRW/month) 2. 50 KRW/km (65,000 KRW/month) 3. 100 KRW/km (130,000 KRW/month) 4. 150 KRW/km (195,000 KRW/month)
Fuel charging accessibility	Description	Percentage of gas and charging stations available for the vehicle compared to the total number of gas stations currently available
	Level (3)	1. 100% 2. 50% 3. 10%
Maximum drivable distance	Description	Maximum mileage after a single charge
	Level (4)	1. 400km 2. 600km 3. 800km 4. 1,000km
Vehicle price	Description	Total cost for purchasing a vehicle excluding all the tax and insurance
	Level (4)	1. 20million KRW 2. 35million KRW 3. 50million KRW 4. 65million KRW

From the listed attributes and their levels in Table 2, a total number of 4,608 different combinations of attributes can be formed. However, in order to enable respondents to make accurate judgments under limited physical constraints, a fractional factorial design was conducted to extract 32 alternatives. The alternatives were then arranged into eight choice sets with four different alternatives in each choice set. Four choice sets or 16 alternatives among eight choice sets, or 32 alternatives, were then randomly distributed to two different groups of sample respondents. An example of a choice set consisting of four different alternatives that were used in the choice experiment of this study is depicted in Figure 4.

Q. Please choose the most preferred vehicle type from the four hypothetical options provided below. Note: Assume that all the other attributes besides the seven are the same.

▣ **Sample Card**

Choice set 1	**Vehicle A**	**Vehicle B**	**Vehicle C**	**Vehicle D**
1. Fuel type	ICEV	ICEV	EV	HFCV
Source of energy (EV & HFCV)			Expansion in renewable energy generation mix	SMR-oriented hydrogen production mix
2. Charging time (minutes)	40 minutes	5 minutes	5 minutes	20 minutes
3. Fuel cost (KRW/km)	100 KRW/km	25 KRW/km	100 KRW/km	50 KRW/km
4. Fuel charging accessibility (%)	50%	10%	100%	10%
5. Maximum drivable range (km)	1,000km	600km	400km	600km
7. Purchase price (KRW)	35million KRW	65million KRW	35million KRW	50million KRW
Choose the most preferred type	**Type A**	**Type B**	**Type C**	**Type D**

Figure 4. Example of sample choice set used in the experiment (translated from Korean)

3.3 Model Specification

The main methodology used in this study to analyze consumers' purchasing behavior of the various fuel types of vehicles in South Korea is the mixed logit model. The mixed logit model is one of the models developed from the logit model, which is based on an individual's utility maximizing behavior. Utility, denoted as U_{nj}, is the level of utility that respondent, n, would have when he or she chooses alternative j. Composition of the utility, U_{nj}, can be described as Eq. (1).

$$U_{nj} = V_{nj} + \varepsilon_{nj} = \sum_k \beta_{nk} x_k + \varepsilon_{nj} \quad \text{Eq. (1)}$$

V_{nj} describes the observable part of the utility of the respondent n and ε_{nj} expresses the unobservable part of the utility of the respondent n. The observable utility, V_{nj}, consists of the values of each attribute x_k multiplied by the attribute coefficient β_{nk}. Under the utility maximizing behavior of each individual, the rational individual would choose an alternative that would give the maximum value of utility to him or her. In other words, all the other alternatives, except for alternative j, that the individual would choose cannot give more levels of utility than alternative j, which can be expressed as Eq. (2).

$$P_{nj} = \Pr(U_{nj} > U_{ni}, \forall i \neq j) = \Pr(V_{nj} - V_{ni} > \varepsilon_{ni} - \varepsilon_{nj}, \forall i \neq j) \quad \text{Eq. (2)}$$

In the logit model, ε_{nj} is assumed to be independent and identically distributed with having extreme value, with a probability density function of $f(\varepsilon_{nj}) = e^{-\varepsilon_{nj}} e^{-e^{-\varepsilon_{nj}}}$ and a cumulative density function of $F(\varepsilon_{nj}) = e^{-e^{-\varepsilon_{nj}}}$, (Train, 2009). Modification of Eq. (2) to Eq. (3) shows that the P_{nj} is the cumulative distribution for each ε_{ni} evaluated at $V_{nj} - V_{ni} + \varepsilon_{nj}$, denoted as $e^{-e^{-(\varepsilon_{nj}+V_{nj}-V_{ni})}}$.

$$P_{nj} = \Pr(V_{nj} - V_{ni} + \varepsilon_{nj} > \varepsilon_{ni}, \forall i \neq j) \quad \cdots\cdots \text{Eq. (3)}$$

The cumulative distribution consequently yields the probability that individual n chooses alternative j, which is a formula of the standard logit model, Eq. (4).

$$L_{nj}(\beta_n) = \frac{\exp(\beta_n' x_{nj})}{\sum_i \exp(\beta_n' x_{ni})} \quad \cdots\cdots \text{Eq. (4)}$$

Although the logit model is the most widely used discrete choice model, the mixed logit model has an advantage over the logit model in terms of reflecting an individual's heterogeneous aspects more realistically, by assuming different coefficients β_{nk} of each decision maker for attribute x_k. If coefficients are assumed to have a density function $f(\beta)$, which gives different weights to different values of β, then choice probability under the mixed logit model would be integrals of standard logit probabilities over a density of parameters. Therefore, an individual's choice probability in the mixed logit model can be expressed in the form of Eq. (5), where n stands for individual and j indicates an alternative that n would choose.

$$P_{nj} = \int \left(\frac{\exp(\beta_n' x_{nj})}{\sum_i \exp(\beta_n' x_{ni})} \right) f(\beta_n) d\beta_n \quad \cdots\cdots \text{Eq. (5)}$$

To empirically analyze consumers' preferences using a mixed logit model, the process of figuring out the relative importance and marginal willingness of a consumer to pay for certain attributes of an alternative is required. Of relative importance, it is possible to capture the amount of influence each attribute has on an individual's choice. The relative importance RI_k of an attribute x_k can be calculated by multiplying by 100 after dividing the part-worth of the attribute by the sum of the total part-worth, as in Eq. (6). In addition, the part-worth of attribute x_k is the absolute value of difference between the minimum and maximum levels of attribute x_k multiplied by the coefficient β_{nk} (Kim et al., 2020).

$$RI_k = \left(\frac{part-worth_k}{\sum_k part-worth_k} \right) \times 100 \cdots\cdots \text{Eq. (6)}$$

A marginal willingness to pay (MWTP) is the amount that a consumer would like to pay for maintaining the current level of utility when there is change in the level of an attribute with one unit (Shin et al., 2014). MWTP allows researchers to more easily figure out consumers' preferences for attributes, as it can change the level of utility that consumers feel about particular attributes and their bearing on monetary units. MWTP is typically derived through Eq. (7), where x_{jk} and β_{jk} refer to attribute k of alternative j and its coefficient parameter, respectively. In addition, $x_{j,price}$ and $\beta_{j,price}$ refer to price attributes of alternative j and its coefficient parameter.

$$MWTP_{x_{jk}} = -\frac{\partial U_{nj} / \partial x_{jk}}{\partial U_{nj} / \partial x_{j,price}} = -\frac{\beta_{jk}}{\beta_{j,price}} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{ Eq. (7)}$$

The mixed logit model allows researchers to capture the individuals' heterogeneous preference over the attributes. This aspect can also be applicable in estimating the MWTP when the mixed logit model is utilized. Based on the individual n 's coefficient β_{njk} for attribute k, the MWTP values $MWTP_{x_{njk}}$ for every respondent can be estimated. Based on the MWTP for all the respondents, the median value of the $MWTP_{x_{njk}}$ can be calculated as Eq. (8).

$$Median\ MWTP_{x_k} = Median_n \left[-\frac{\partial U_{nj} / \partial x_{jk}}{\partial U_{nj} / \partial x_{j,price}} \right] = Median_n \left[-\frac{\hat{\beta}_{njk}}{\hat{\beta}_{nj,price}} \right] \quad \cdots\cdots\cdots \text{ Eq. (8)}$$

(Train & Weeks, 2005) proposed a new approach of estimating the MWTP, by using $WTP-space$. The above mentioned $MWTP_{x_{njk}}$, which is known as WTP in preference space or $\beta-space$ is usually derived by taking the negative value of the ratios of the non-price attributes coefficients and the price coefficient (Bazzani et al., 2018). To understand the $WTP-space$ approach, process of re-organizing the utility function in Eq. (1) by separating the price attribute from V_{nj} is required. Then the utility of respondent n choosing an alternative j can be expressed as a form of utility function like Eq. (9), where c_n is scale parameter for decision maker n.

$$U_{nj} = V_{nj} + \varepsilon_{nj} = -(\alpha_n / c_n) p_{nj} + (\beta_n / c_n)' x_{nj} + \varepsilon_{nj} = -\lambda_n p_{nj} + r_n' x_{nj} + \varepsilon_{nj} \quad \cdots\cdots\cdots \text{ Eq. (9)}$$

Under the new form of utility function, the MWTP of $\beta - space$ approach can be known as $w_n = \left({r_n}/{\lambda_n} \right)$. However, in $WTP - space$, the utility function is re-parameterized as Eq. (10), which makes the attribute coefficients ($\lambda_n w_n$) can be directly interpreted as MWTP values (Scarpa & Wills, 2010). By doing so, the price/scale coefficient (λ_n) becomes random, which helps to overcome the problem of confounding distributional assumptions of price and scale parameters usually occur in $\beta - space$ (Bazzani et al., 2018).

$$U_{nj} = -\lambda_n p_{nj} + (\lambda_n w_n)' x_{nj} + \varepsilon_{nj} \quad \cdots\cdots \text{Eq. (10)}$$

As mentioned before, utility maximizing behavior assumes that a decision maker chooses an alternative that maximizes his or her utility when the decision maker faces several alternatives from which to choose. When applying this utility maximization behavior into the choice experiment conducted by this study, the respondent's utility toward a vehicle that he or she would select can be specified as Eq. (11).

$$\begin{aligned} U_{nj} = {} & \beta_1 d_{j,EV\_current} + \beta_2 d_{j,EV\_nuclear} \\ & + \beta_3 d_{j,EV\_renewable} + \beta_4 d_{j,HFCV\_SMR} \\ & + \beta_5 d_{j,\_electrolysis} + \beta_6 x_{j,charging\_time} \\ & + \beta_7 x_{j,fuel\_price} + \beta_8 x_{j,accessibility} \\ & + \beta_9 x_{j,driveable\_range} + \beta_{10} x_{j,vehicle\_price} + \varepsilon_{nj} \end{aligned} \quad \cdots\cdots \text{Eq. (11)}$$

In Eq. (11), utility U_{nj} of the respondent n when he or she chooses alternative j is composed of different variables d_{jk} and x_{jk} with their vector coefficients β_n and the stochastic term ε_{nj} . The variables $d_{j,EV\_current}$, $d_{j,EV\_nuclear}$, $d_{j,EV\_renewable}$, $d_{j,HFCV\_SMR}$, and $d_{j,HFCV\_electrolysis}$ are dummy variables indicating the fuel types of vehicle with its power mix and production mix (EV and HFCV only). We set a baseline variable for dummy variables as ICEV, in order to compare the consumers preference among the conventional fuel types with the alternative fuel types more sophisticatedly. These dummy variables take the value of 1 when the decision maker chooses one of the variables, and 0 otherwise. For instance, if the decision maker chooses EV with current generation mix as an alternative, then all the dummy variables than $d_{j,EV\_current}$ take the value of 0. Moreover, if the decision maker chooses ICEV for the fuel type of a vehicle, then all the dummy variables in Eq. (11) take the value of 0. The variables x_{jk} are linear variables that indicate each attribute of alternative j .

Unlike the other logit models which comprehensively assume that the coefficients are assumed as normal distributed, mixed logit model has an advantage that it can assume every different distribution for the coefficients of each variable (McFadden & Train, 2000). For instance, coefficients of attributes that every individual is likely to prefer a higher level, such as wage, infrastructure, and education should be assumed as a log-normal distribution (Hole and Kolstad, 2012).

In this paper, coefficients of variables regarding the fuel type (ICEV, EV, HFCV) and their energy sources mix (EV: current mix, nuclear power reduction mix, renewable energy expansion mix, HFCV: SMR-oriented mix, electrolysis-oriented mix) are assumed as normal distribution as respondents' preferences over the variables can be different among the respondents. However, respondents are likely to prefer a lower level of attributes like charging time, fuel cost, and vehicle price, whereas respondents are likely to prefer a higher level of attributes like charging station accessibility and maximum drivable distance. Since these variables have same directions of preferences for every respondent as the level of the attributes change, we assumed the coefficients of them are distributed as a log-normal distribution. Table 3 summarizes the description of the variables and their distributions.

Table 3. Description of variables used in the mixed logit model

Variable	Description	Distribution
$d_{j,EV\_current}$	Dummy variable If the respondent chooses the EV with current generation mix 1, if not 0.	Normal distribution
$d_{j,electric\_nuclear}$	Dummy variable If the respondent chooses the EV with nuclear power reduced generation mix 1, if not 0.	Normal distribution
$d_{j,electric\_renewable}$	Dummy variable If the respondent chooses the EV with renewable energy-oriented generation mix 1, if not 0.	Normal distribution

$d_{j,hydrogen\_SMR}$	Dummy variable If the respondent chooses the HFCV with SMR-oriented production mix 1, if not 0.	Normal distribution
$d_{j,hydrogen\_electrolysis}$	Dummy variable If the respondent chooses the HFCV with electrolysis-oriented production mix 1, if not 0.	Normal distribution
$x_{j,charging\_time}$	Linear variable Charging time of the vehicle (5, 20, 40, 60)	Log-normal distribution
$x_{j,fuel\_price}$	Linear variable Price of fuel for the vehicle (25, 50, 100, 150)	Log-normal distribution
$x_{j,accessibility}$	Linear variable Accessibility of charging station (100, 50, 10)	Log-normal distribution
$x_{j,driveable\_range}$	Linear variable Maximum drivable range of the vehicle (400, 600, 800, 1000)	Log-normal distribution
$x_{j,vehicle\_price}$	Linear variable Price of the vehicle (2000, 3500, 5000, 6500)	Log-normal distribution

To estimate the parameters of each variables from the mixed logit model, Maximum Likelihood Estimation (MLE) and Bayesian Estimation Method are commonly used. Since MLE provides estimates closest to the true parameters in Kullback-Leibler criterion, this study utilized MLE as an estimation method (Park and Gupta, 2009). Train (2009) presented the estimation procedure of the mixed logit model by MLE as follows.

From choice probability of the mixed logit model Eq. (5), a β_n can defined as distributed with density $f(\beta|\theta)$, which transforms the choice probability, Eq. (5) into Eq. (12). Then, the simulated probabilities $L_{nj}(\beta^r)$ are approximated by drawing a value of β from $f(\beta|\theta)$, where r refers to the number of draws (Train, 2003).

$$P_{nj} = \int \left(\frac{\exp(\beta_n' x_{nj})}{\sum_i \exp(\beta_n' x_{ni})} \right) f(\beta|\theta) d\beta \quad \cdots\cdots \text{Eq. (12)}$$

By inserting an average value of the simulated probability, Eq. (13), into the log-likelihood function, we can derive a simulated log likelihood (SLL) as Eq. (14).

$$\breve{P}_{nj} = \frac{1}{R} \sum_{r=1}^{R} L_{ni}(\beta^r) \quad \cdots\cdots \text{Eq. (13)}$$

In Eq. (14), d_{nj} indicates whether a respondent n chooses an alternative j with taking a value of 1 when the alternative is chosen and zero otherwise. The maximum simulated likelihood estimator (MSLE) is the θ value of θ that maximizes SLL, which will be estimated in the analysis section (Train, 2009).

$$\text{SLL} = \sum_{n=1}^{N} \sum_{j=1}^{J} d_{nj} \ln \breve{P}_{nj} \quad \cdots\cdots \text{Eq. (14)}$$

Chapter 4. Analysis and Results

In this chapter, an empirical analysis of this study will be discussed. First of all, in Chapter 4.1, the data that are mainly used for the analysis are be described. Descriptive statistics of the respondents from the choice experiment will be summarized. Moreover, the levels of GHG emissions by the various hydrogen production methods which will be utilized for the further GHG emission analysis are also explained. In Chapter 4.2, the estimation results of mixed logit model are mainly presented. The results show the general preferences of consumers toward purchasing vehicles. In addition, consumers' marginal willingness to pay for each attribute is also analyzed for further ex-ante simulation. Lastly, in Chapter 4.3 the ex-ante simulation will be conducted along with the background of performing scenario analysis. In this chapter, simulation analysis will be proceeded in two different perspectives, capturing the diffusion trend of HFCVs by the levels of attributes change and examining environmental impact of HFCVs along with their diffusion.

4.1 Collection of Data

4.1.1 Descriptive Statistics

To collect the data about consumers' preferences on vehicle types, this study conducted a discrete choice experiment as mentioned earlier. The data was acquired through one-to-one survey. Gallup Korea, a professional survey company, conducted the survey during the second week of November 2020. Respondents for the survey were extracted from men and women ages 20 to 69 among the people who live in South Korea. The extraction of samples from the population was acquired through purposive quota sampling method in order to secure the representativeness of South Korean population and the total number of sample respondents was 455. Table 4 depicts the socio-demographic characteristics of 455 respondents.

Table 4. Socio-demographic characteristics of respondents

		Responses	Percentage
Total		455	100%
Gender	Male	237	52.1%
	Female	218	47.9%
Age	20–29	96	21.1%
	30–39	131	28.8%
	40–49	130	28.6%
	50–59	67	14.7%
	60–69	31	6.8%
Monthly income	Less than 3 million KRW	125	27.5%
	3 million–4 million KRW	72	15.8%
	4 million–5 million KRW	76	16.7%
	More than 5 million KRW	182	40.0%

Residential region	Seoul	154	33.8%
	Metropolitan Cities	107	23.5%
	Sejong Metropolitan Autonomous City	4	0.9%
	Gyeonggi	115	25.3%
	Chungcheong	17	3.8%
	Jeolla	21	4.6%
	Gangwon	8	1.8%
	Gyeongsang	26	5.7%
	Jeju	3	0.7%

4.1.2 GHG Emissions by Hydrogen Production Methods

In order to assess the environmental performance of HFCVs, it is necessary to know the amount of GHG emissions emitted from the hydrogen production process. There are several different hydrogen production methods which are utilizing the byproduct hydrogen obtained from the oil refining process, reforming the hydrogen obtained from natural gas (SMR), and utilizing electricity from renewable energy to extract hydrogen (electrolysis). Here, we would like to look at the GHG emission from the SMR-method and electrolysis-method of hydrogen production, since byproduct hydrogen in South Korea is mainly used in the industrial field. Shin et al., (2019) used the MDCEV model to compare the environmental characteristics of EVs and HFCVs and to estimate GHG emissions from consumers' driving patterns. They estimated the GHG emissions for AFVs using the data of GHG emissions per kilogram of hydrogen by different production methods that were calculated from Cetinkaya et al. (2012). In this study, we also referred to the GHG emissions data for each hydrogen production method based on the study of Cetinkaya et al. (2012). In this study, we consider all the upstream process of each hydrogen production methods in order to examine the environmental impacts in WTW perspective. The amount of GHG emissions to produce one kilogram of hydrogen by the SMR process and electrolysis process are summarized in Table 5.

Table 5. GHG emissions by different hydrogen production methods

GHG emissions (g/kg H2)	GHG components	SMR	Electrolysis (Renewable Energy)
Amount of GHG emissions to produce 1kg of hydrogen	CO2	9358.66	950
	CO	1.26	0.90
	NOx	4.07	4.75
	CH4	59.80	0.30

4.2 Estimation Results

4.2.1 General Consumer Preference for Vehicles

This study used a mixed logit model to estimate the coefficients of each variable. By using the utility function described in Eq. (8) and the assumed distributions of each variables' coefficients summarized in Table 3, the maximum loglikelihood estimation was conducted. The estimation results derived from this study are shown in Table 6. The estimation procedure was carried out through using the statistics package, STATA 16.1.

Table 6. Estimation results of mixed logit model

Variables	Mean (b)		Std. Deviation ($\sqrt{W}$)	
	Coef.	Std. Err.	Coef.	Std. Err.
Baseline (ICEV)	-	-	-	-
β_1 (EV-current generation mix)	0.33234***	0.0993	0.0110	0.2561
β_2 (EV-reduction in nuclear power mix)	0.18362	0.1655	1.30011***	0.3405
β_3 (EV-expansion in renewable energy mix)	0.58485**	0.0902	0.46730**	0.2147
β_4 (HFCV- SMR oriented mix)	-0.11614	0.1571	1.12583***	0.2566
β_5 (HFCV-electrolysis oriented mix)	-0.17984	0.1657	1.30155***	0.2727
β_6 (fuel charging time)	-0.01629**	0.0031	0.04211	0.0274
β_7 (fuel cost)	-0.01238**	0.0055	0.14784	0.2299
β_8 (fuel charging accessibility)	0.00394***	0.0010	0.00510**	0.0245
β_9 (maximum drivable range)	0.00023	0.0002	0.00004*	0.0002
β_{10} (vehicle price)	-0.00048***	0.0001	0.00194	0.0013

Note: ***Significant at the 1% level, **Significant at the 5% level, *Significant at the 10% level

According to the result, consumers are likely to prefer the EVs operated by the current generation mix and renewable oriented mix than ICEVs, and HFCVs operated by both production mix. Consumers prefer EVs operated by the current generation mix more than EVs operated by the generation mix with the nuclear power is reduced substantially, whereas there was significantly more preference in EVs operated by the generation mix with the share of renewable energy is expanded substantially than EVs operated by other generation mixes. This implies that the government should promote the diffusion of EVs in a way that emphasizes the link between EVs and renewable energy, while shift in power mix should move toward drastically increasing the share of renewable energy rather than drastically reducing the share of nuclear power. Among the HFCVs, there was no difference in the preferences of consumers toward HFCVs operated by the hydrogen produced from the SMR-oriented mix and HFCVs operated by the hydrogen produced from the electrolysis-oriented mix. Moreover, when compared to the ICEVs, people also do not have the difference in preference between ICEVs and HFCVs. This result implies that Korean consumers consider eco-friendliness only for EVs.

In terms of the attributes of a vehicle, consumers are less likely to prefer when the charging or refueling time for the fuel of their vehicles get longer. Furthermore, consumers are less likely to prefer with the higher fuel cost and higher price of their vehicles. Lastly, consumers do prefer with the increased accessibility of their fuel types of charging stations. However, for the maximum drivable distance of a vehicle with a single charge, it does not appear to be statistically significant at the 10% confidence level. This result might can be seen as that Korean drivers do not care much about the maximum drivable range since Korean national land area is relatively small and there is not much distance to travel in a day for the drivers. Overall directions of the preferences for each attribute are consistent with the assumption of directions that we had previously considered when setting their coefficients' distributions as lognormally distributed.

4.2.2 Marginal Willingness to Pay

Based on the parameter estimation in Chapter 4.2.1, we also estimated the MWTP of consumers for each attribute of the vehicle. The mixed logit model can specify the differences in preference for every individual by examining their preferences in the individual level. Therefore, we can derive the median value of the MWTP from the $\beta - space$. The estimated values of the MWTP are presented in Table 7.

Table 7. MWTP values for attributes

Level of Attributes Change	Median $MWTP_{x_k}$ from $\beta - space$
ICEV → EV-current generation mix	19,195,522
ICEV → EV-reduction in nuclear power generation mix	1,320,563
ICEV → EV-expansion in renewable energy mix	31,373,223
ICEV → HFCV- SMR oriented mix	-12,662,090
ICEV → HFCV-electrolysis oriented mix	-13,429,756
1 minute of fuel charging time increase	-559,076
1 % of increase in fuel charging accessibility	202,908
1 km of increase in maximum drivable distance	13,143

Note: Units of all the MWTP values are KRW

The MWTP estimates for charging time and maximum drivable distance implies about the technological improvement of the vehicles. Consumers are willing to pay about 559 thousand KRW, if one minute of charging time of the vehicle reduces. For the maximum drivable distance, consumers are willing to pay about 13 thousand KRW for 1km of improvement. These two attributes are mainly related the strategies of the manufacturers of vehicles since they are related to the technological issues. In terms of infrastructure accessibility of charging stations is mainly considered. Consumers are willing to pay about 202 thousand KRW to increase 1% of charging station accessibility. In case of the fuel cost, the MWTP of fuel cost cannot be derived since it is monetary value. The aforementioned MWTP values are based on the median MWTP from the individual level's preference space.

4.3 Scenario Analysis

4.3.1 Scenario Background

In Chapter 4.3, we will simulate the future state of HFCVs by utilizing the estimation results and related data from the prior analysis. There are two main streams of scenario analysis in this study. The first scenario analysis is examining the future diffusion trend of HFCVs by differing the attribute levels of HFCVs. Based on this examination, we would like to find out which direction is appropriate for the government to take under the objective of expanding the supply of HFCVs. Moreover, assessing policy feasibility of the government invest in the hydrogen economy will be also conducted by considering consumers' welfare. The second scenario analysis is examining the environmental impact from diffusion of HFCVs by different hydrogen production mix. Though it is fact that there are more GHG emissions in the hydrogen production in the SMR process than electrolysis process, it has yet to be studied to what extent these GHG emissions differ as HFCVs are diffused in the near future. Therefore, in the second part of the ex-ante simulation, amount of GHG emissions from HFCVs by different hydrogen production methods will be assessed based on the overall attributes level changes in both EVs and HFCVs to figure out the future state of AFVs. Furthermore, the environmental impact of changes in the production mix of hydrogen for HFCVs is not only presented by GHG emissions, but also by reflecting the environmental cost coefficients contained in each GHG, the feasibility of the hydrogen production method is also be compared to the cost of each method.

For the baseline scenario which is the current state of each fuel type of vehicle, we used the current data of each vehicle type. For instance, vehicle price of each fuel type was set based on the most popular model from mid-size 2000cc in the South Korean vehicle market. Currently, the most popular model for the ICEVs is K5 manufactured by KIA Motors, and it for the EVs is Niro manufactured by KIA Motors. In case of HFCVs, there is only one model available in the South Korean vehicle market, which is Hyundai Nexo. Therefore, we set the price of each fuel type as 30 million KRW, 50 million KRW, and 70 million KRW, respectively. Fuel cost levels for each vehicle type was calculated based on the current price of each fuel type and their fuel economy. ICEVs which consists of gasoline and diesel costs about 100 KRW per kilometer. EVs take about 40 KRW per kilometer when considering only high-speed battery charge. For HFCVs, which require about 6kg of hydrogen to drive 600km, the cost per 1km driving is about 80 KRW. In case of refueling and charging time of vehicles, ICEVs take about 3 minutes, HFCVs take about 5 minutes, while EVs take about 80 minutes though it was proceeded by the high-speed charging equipment. Maximum drivable ranges of each vehicle types were calculated based on the popular model of each fuel type, and for the ICEV's drivable range was average value of the diesel type of K5 and gasoline type of K5 sold in 2019. Therefore, we set the maximum drivable distance for each fuel type as 800km, 300km and 600km for each. Lastly, the charging accessibility for EVs and HFCVs are calculated based on the ratio of the number of (high-speed) electric charging stations and hydrogen charging stations to the current number of gas stations. We referred to the ev.or.kr to find out the current status of each charging station, and the number of charging stations was about 1,800 and 31 for EVs and HFCVs, respectively. Table 8 summarizes the overall levels of attributes for each fuel type in the baseline scenario.

Table 8. Levels of attributes for each fuel type in baseline scenario

	Charging time	Fuel cost	Charging access.	Drivable range	Vehicle price
ICEV	3 mins	100 KRW/km	100%	800km	300million KRW
EV	80 mins	40 KRW/km	15%	300km	500million KRW
HFCV	5 mins	80 KRW/km	0.26%	600km	700million KRW

This study referred to the Hydrogen Economy Road Map and Strategy for the Development of the Future Automotive Industry announced by the South Korean government in 2019, to set the scenarios for the future state of AFVs' attributes. According to the government plans, Korean government aims to supply about 65 thousand HFCVs by 2022 and 2.9 million HFCVs by 2040. In terms of vehicle price, the government plans to lower the price of HFCVs to the level of EVs by 2023 and to the level of ICEVs by 2030. The price of hydrogen fuel is aimed to be lowered to 6,000 KRW/kg in 2022 and 4,000 KRW/kg in 2030. The plan for the charging accessibility of hydrogen fuel is to expand the number of hydrogen fuel stations about 310 stations by 2022, 660 stations by 2030 and about 1,200 stations by 2040. For the maximum drivable distance of HFCV, it is expected to be increased by 800km with a single charge, which is about 200km more range compared to the current HFCV's drivable range. In the case of hydrogen production mix, the government declared extracted hydrogen as a key source of hydrogen economy in the early stage while gradually making South Korea as a green hydrogen producing country in the near future.

With regard to EVs, the government plans to increase EV's maximum drivable range to 600km in 2030, and its (high-speed) charging time to 20 minutes by increasing the electric power output capability. For charging infrastructure of EVs, the government plans to increase the number of high-speed charging facilities about 10,000 by 2030. Since, there is about 3~4 facilities for one station, we set the number of electric charging stations as 3,000, which is about 30% compared to the number of gas stations. Regarding the charging price for EVs, the government's recent action for the EV charging fees, which was increasing the fee about 20%. Moreover, as the government declared to suspend the discount of EV charging fee from 2022, we set the fuel cost of EVs will be about 80 KRW/km in 2030. In the case of ICEVs, we used the baseline attribute levels as the same in the near future, since there was no regarding government plan about ICEVs. To sum up, the future state (2030) of AFVs is summarized in Table 9.

Table 9. Attributes for AFVs in the future state (2030)

	Charging time	Fuel cost	Charging access.	Drivable range	Vehicle price
EV	20 mins	80 KRW/km	30%	600km	500million KRW
HFCV	5 mins	40 KRW/km	5%	800km	700million KRW

Note: Future vehicle price is not included in the future state scenario analysis.

4.3.2 Diffusion Trend of HFCVs by the Attribute Changes

First of all, based on the estimation results in Chapter 4.2, the choice probability of each fuel type or market share of each fuel type in current status (Figure 5) were calculated by reflecting the current attribute levels for each vehicle type. 75.79% of consumers are expected to purchase ICEVs, 18.09% of consumers are expected to purchase EVs, and 6.12% of consumers are expected to purchase HFCVs. From the three-year average value of increased number in vehicle registration data, we calculated the number of new vehicles that are expected to be registered in a year, which are 395,715, 94,451, and 31,954 for ICEVs, EVs, and HFCVs, respectively.

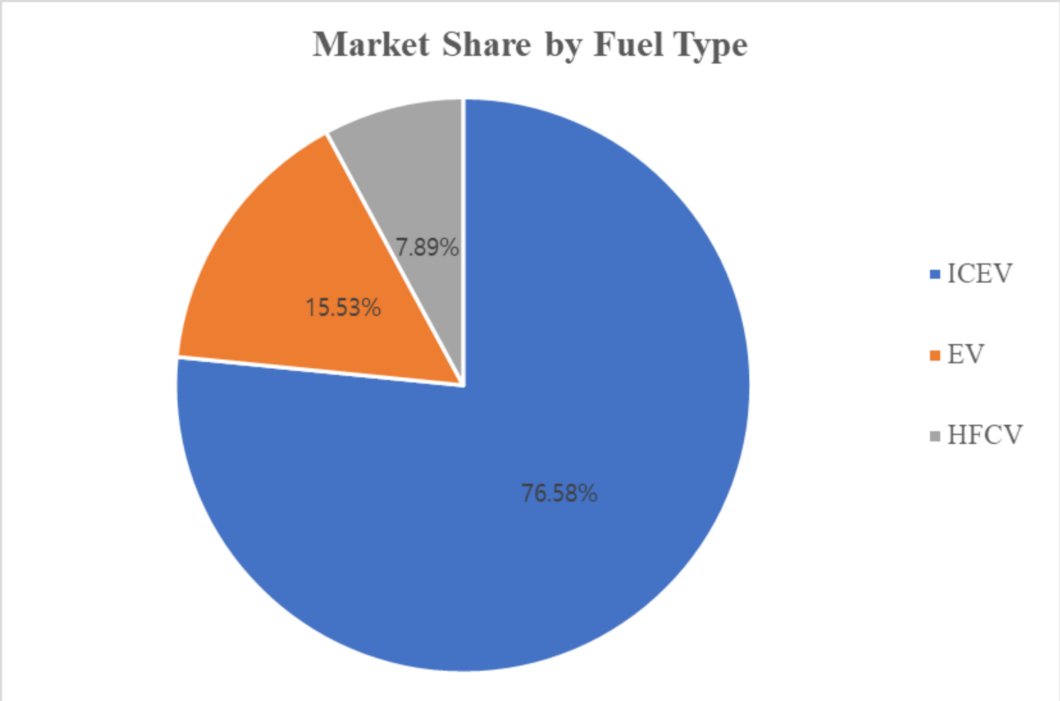


Figure 5. Market share by the fuel types of vehicles under baseline scenario

A total of five scenarios are set in this chapter to figure out the trend of HFCVs proliferation as the level of attributes of HFCVs changed. We first defined a base scenario with the current level of attributes to compare the other types of scenarios. Other four scenarios are defined as the future scenarios based on the government plan discussed in the Chapter 4.3.1. In order to see how the changes in individual aspect of the attributes affect the diffusion trend of HFCVs, we assumed only one change of attribute level for each scenario. Scenario 1 assumed the maximum drivable distance of HFCVs is increased by 800km. Scenario 2 assumed the fuel cost of HFCVs is reduced by 40 KRW/km. Scenario 3 assumed the accessibility of hydrogen charging stations is increased by 5%

(about 600 stations). Scenario 4 assumed that the price of HFCVs would fall to the level of ICEV. To be more realistic, we assumed that the price of HFCVs would be reduced to 40 million KRW, which is close to the representative price of ICEVs (30 million KRW).

Scenario 1: Assuming the government plan for the maximum drivable distance of HFCV is achieved in 2030. (600km → 800km)

Scenario 2: Assuming the government plan for the fuel cost of hydrogen is achieved in 2030. (80 KRW/km → 40 KRW/km)

Scenario 3: Assuming the government plan for the accessibility of hydrogen charging station is achieved in 2030. (0.25% → 5%)

Scenario 4: Assuming the government plan for the price of HFCVs is achieved in 2030. (70 million KRW → 40 million KRW)

Table 10. Scenario analysis for the diffusion trend

		ICEV (Gasoline & Diesel)	EV	HFCV
Baseline scenario	Market Share	76.58%	15.53%	7.89%
	Number of newly registered vehicles	399,840	81,085	41,195
Scenario 1	Market Share	76.30%	15.47%	8.23%
	Number of newly registered	398,378 (-1,462)	80,772 (-313)	42,970 (+1,775)

	vehicles (Changes in vehicle numbers)			
Scenario 2	Market Share	72.90%	14.78%	12.32%
	Number of newly registered vehicles (Changes in vehicle numbers)	380,626 (-19,214)	77,169 (-3,916)	64,325 (+23,130)
Scenario 3	Market Share	76.47%	15.51%	8.02%
	Number of newly registered vehicles (Changes in vehicle numbers)	399,265 (-574)	80,981 (-104)	41,874 (+679)
Scenario 4	Market Share	60.91%	12.35%	26.74%
	Number of newly registered vehicles (Changes in vehicle numbers)	318,023 (-81,816)	64,482 (-16,603)	139,615 (+98,420)

According to the scenario analysis results by each attribute level changes for the HFCV in Table 10, under the HFCV's attribute level in regard of government's hydrogen activation roadmap objective, in the order of price of HFCVs, hydrogen fuel cost, maximum drivable range, and infrastructure of hydrogen charging station was analyzed to be effective. Since, the impact of charging accessibility of HFCVs was quite low for the diffusion of HFCVs, we conducted more specific simulation focusing on the charging accessibility level. To increase the 1% of market share of HFCVs from the current state, about 3,500 more hydrogen charging stations are required. This implies that the inconvenience associated with charging infrastructure of hydrogen might not be very touching for those who have not own HFCVs yet, or that consumers do not consider much when purchasing a vehicle.

However, the diffusion trend of HFCVs seen previous has difficulty in weighing the policy feasibility and efficiency since there is no comparison with the budget or consumers' welfare. Thus, a slightly more advanced analysis was conducted, including the government's budget and the consumers' welfare, to analyze the policy feasibility and efficiency of infrastructure expansion and fuel cost discount of HFCVs. First, we calculated the cumulative numbers of HFCVs by Scenario 2 and Scenario 3, to figure out the total increased number of HFCVs, which is depicted in Figure 6. Then, based on the increased number of HFCVs in Scenario 2, the amount of budget required to discount the charging fee of hydrogen fuel was estimated, reflecting the average annual driving distance in South Korea. In order to calculate the budget for Scenario 3, we multiplied 3 billion KRW for installing one hydrogen charging station by the number of required charging stations. The consumer surplus was calculated from multiplying the median MWTP value of consumers for each attribute with the increased level of the attribute and the total increased number of HFCV consumers by Scenario 3.

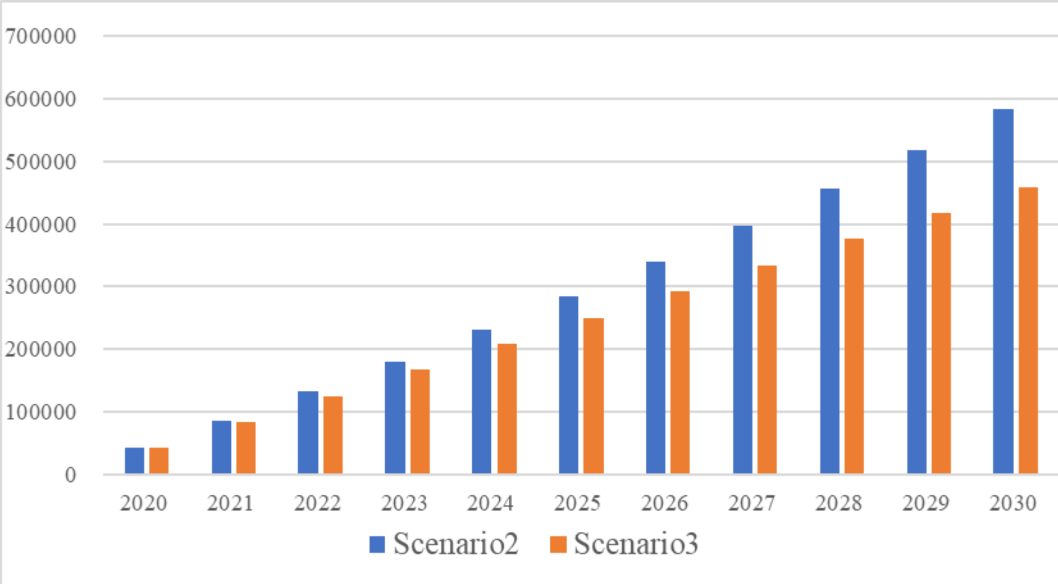


Figure 6. Total registered number of HFCVs under Scenarios 2 and 3

According to the analysis of policy feasibility and efficiency regarding the budget, total increased number, and consumer surplus, the results are as follows. It will take about 1.33 trillion KRW of budget to gradually reduce the cost of hydrogen fuel to 40 KRW/km by 2030, while it will take about 1.7 trillion KRW of budget to expand 600 charging stations for HFCV by 2030. It will cost 2.46 million KRW to proliferate one HFCV when the policy is focused on lowering fuel costs, while it will cost 4.07 million

KRW to proliferate one HFCV when the policy is focused on expansion of charging station infrastructure. Therefore, under the government objective of supplying HFCVs, it is expected that the policy focusing on lowering the fuel costs of hydrogen will be about 1.5 time more efficient than increasing the accessibility of hydrogen charging stations. In terms of consumer welfare in 2030, only the Scenario 3 is considered as it is based on consumers' MWTP for each attribute. The consumer surplus is about 154 billion KRW under the policy of expanding charging infrastructure of HFCVs. Therefore, if the consumer surplus is compared to the total budget required for the policy of expanding the infrastructure of HFCVs, it seems that the policy of the expanding the charging stations is not feasible. Table 11 summarizes the comparison about the efficiency and feasibility of policy regarding the hydrogen economy.

Table 11. Comparison of policy efficiency and feasibility by Scenarios 2 and 3

	Cumulative number (Increased number)	Total budget	Budget for diffusing one HFCV	Consumer surplus
Scenario 2	582,947 (541,282)	1.33 trillion KRW	2.46 million KRW	-
Scenario 3	459,466 (417,800)	1.71 trillion KRW	4.07 million KRW	154 billion KRW

4.3.3 GHG Emission of HFCVs by Hydrogen Production Mix

In this chapter, we explore the environmental impact of HFCVs depending on the hydrogen production mix. To find out the environmental impact, we estimated the more realistic future market share of HFCVs by assuming both EV’s and HFCV’s attribute levels change in 2030. We referred to the Korean government's policy plan outlined in the Chapter 4.3.1 for the changes in the attribute levels of AFVs, and their detailed levels are shown in Table 9. For the generation mix of EVs, we set the renewable-oriented mix as future state to reflect the Korean 8th Powe Supply and Demand Plan. For the hydrogen production mix of HFCVs, with the same levels of attributes other than hydrogen production mix, we compared the choice probability of each fuel type by the hydrogen production mix. For convenience, we define the state of 2030 under SMR-oriented hydrogen production mix as Scenario 5 and the state of 2030 under electrolysis-oriented hydrogen production mix as scenario 6. The choice probabilities of fuel types in Scenario 5 were 56.11% for ICEVs, 33.76% for EVs, and 10.13% for HFCVs. The choice probabilities of fuel types in Scenario 6 were 56.47% for ICEVs, 33.97% for EVs, and 9.56% for HFCVs. This estimation result implies that the diffusion of HFCVs might be slightly slower under the electrolysis-oriented production mix than SMR-oriented production mix. The diffusion trend of total registered number of HFCVs by the hydrogen production mix is depicted in Figure 7.

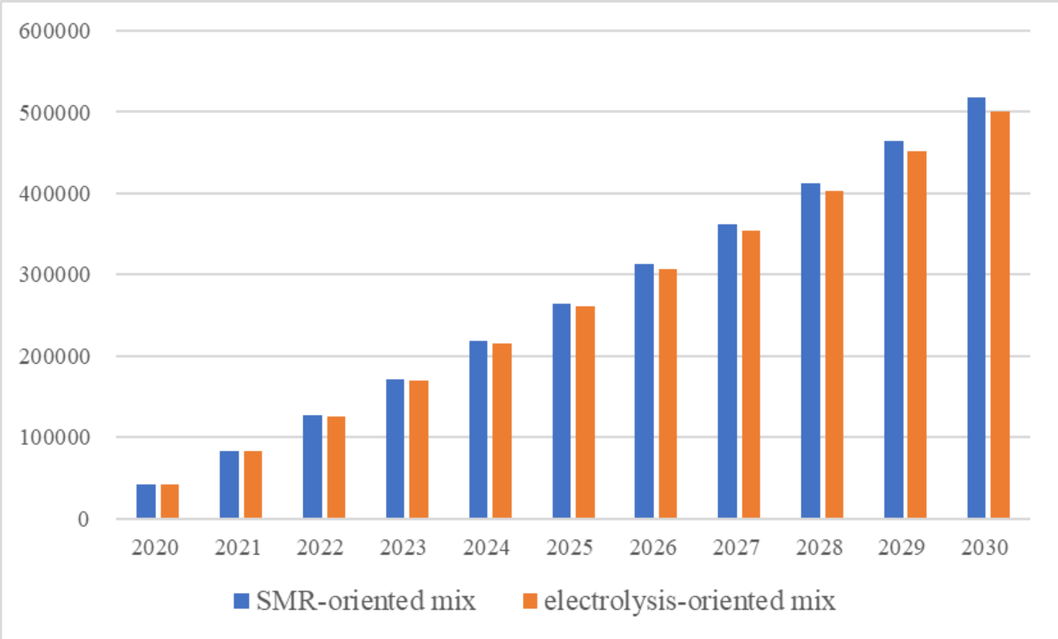


Figure 7. Total registered number of HFCVs by different hydrogen production mix

In the choice experiment conducted by this study, the ratio of hydrogen production mix was considered as a sub-attribute of the fuel type for HFCV as described in Table 2, which makes it difficult to change a single level of hydrogen production mix ratio. Therefore, to identify the cumulative hydrogen usage by Scenarios 5 and 6, we calculated the yearly choice probability of vehicle by assuming that the difference between the choice probability in 2030 and 2020 changes uniformly by a year. Under this assumption, the cumulative registered number of HFCVs by the production mix was estimated, which enabled us to calculate the total annual usage of hydrogen by 2030. According to the statistics from Korean Statistical Information Service (KOSIS), Korean driver’s annual driving range is about 15,800km. Moreover, to drive 100km with HFCVs, about 1kg of hydrogen is required. From this basis, we calculate the annual aggregated usage or demand of hydrogen by each production mix. The detailed values of annual aggregated usage of hydrogen by each production mix are presented in Table 12.

Table 12. Annual aggregated usage of hydrogen under different production mix

Hydrogen usage (unit: ton)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Scenario 5 (SMR-oriented mix)	13,202	20,081	27,144	34,392	41,825	49,443	57,245	65,232	73,404	81,761
Scenario 6 (Electrolysis-oriented-mix)	13,155	19,940	26,862	33,922	41,120	48,455	55,928	63,539	71,288	79,715

We calculated the total cumulative GHG emissions of each production mix from the estimated annual aggregated usage of hydrogen. By considering the ratio of the SMR method and electrolysis method in each production mix, we multiplied the emission rates of GHG by each method that were estimated by Cetinkaya et al. (2012). In case of the electrolysis-oriented hydrogen production mix, we assumed that goal of production mix with 70% of electrolysis hydrogen and 30% of SMR hydrogen is achieved in 2030 with gradually increased share of electrolysis production from the baseline year, 2020. The detailed values of GHG components by different hydrogen production methods are explained in Table 5. According to the calculated GHG emissions by each scenario, HFCVs under the SMR-oriented mix emit about 559 thousand tons of CO2 and HFCVs under the electrolysis-oriented mix emit about 347 thousand tons of CO_2 by 2030. In fact, SMR-oriented mix shows about two times more GHG emissions in terms of carbon dioxide (CO_2) and methane (CH_4), which are fatal to global warming. However, regarding the carbon monoxide (CO) and nitrogen oxide (NO_x), there was less noticeable difference between the two types of hydrogen production mix. Detailed figures for GHG emitted by the increase in the number of HFCVs from different hydrogen production mix are shown in Table 13.

Table 13. GHG emissions of HFCVs under different hydrogen production mix

GHG emissions (unit: ton)	GHG component	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Scenario 5 (SMR-oriented mix)	CO2	90,253	137,274	185,559	235,107	285,918	337,992	391,330	445,930	501,794	558,922
	CO	15	23	31	40	48	57	66	75	85	94
	NOx	56	86	116	147	179	211	245	279	314	349
	CH4	554	842	1,139	1,443	1,755	2,074	2,401	2,736	3,079	3,430
Scenario 6 (Electrolysis-oriented)	CO2	85,507	122,897	156,526	186,254	211,944	233,456	250,650	263,389	271,532	274,941
	CO	15	22	30	37	44	52	59	66	73	80
	NOx	57	86	117	149	181	215	250	285	322	360
	CH4	521	742	935	1,100	1,236	1,341	1,414	1,456	1,464	1,437

Chapter 5. Conclusion

As consensus on the rapidly changing global environment increases by the day, market changes for AFVs are happening faster than expected. Amid these changes, this study is meaningful in that it analyzed in depth the diffusion trend of HFCVs considering the hydrogen production mix of HFCVs along with the environmental performance of HCFVs. Although there is no right answer to the best method of hydrogen production in different countries, due to their different circumstances, we hope that this research will be helpful in that the two objective indicators, environmental and economic feasibility. These two indicators are provided as the criteria for which policies and strategies should be taken into consideration with regard to the promotion of hydrogen economy and HCFVs in different countries.

To recapitulate and summarize the finding of this study as follows: First of all, this study analyzed South Korean consumers preferences toward vehicle types using the mixed logit model, in order to capture the heterogenous preferences among individuals. More specifically, Korean consumers prefer EVs more than ICEVs and HFCVs. In respect to the generation mix of electricity, consumers would likely to drive EVs operated by renewable energy-oriented mix the most, followed by EVs operated from current generation mix and generation mix from substantially reduced nuclear energy. With regard to the production mix of hydrogen, consumers do not have a difference in preference among HFCVs operated with hydrogen produced by the SMR-oriented mix and HFCVs operated with the electrolysis-oriented mix. In terms of this fact alone, we may think that the Korean government needs to take a policy strategy to promote the diffusion of HFCVs, emphasizing the eco-friendliness of the electrolysis-oriented mix HFCVs. However, when we reflected the environmental impact from the diffusion of HFCVs by changing the production mix with assuming the attribute levels at the future, an implication that the government should move in a completely different direction was clarified. The difference in GHG emissions was about twice as high from HFCVs under the SMR-oriented mix than HFCVs under the electrolysis-oriented mix in 2030. This implies that although there are no preference differences between the production mix of HFCVs in Korean vehicle market, the Korean government should gradually promote the electrolysis-oriented mix by 2030, since it can reduce GHG emissions of HFCVs about half under the electrolysis-oriented mix.

Next, we also analyzed the future diffusion trend of HFCVs by differing the levels of attributes for HFCVs. The results provided implications for the government policy aspects as follows. The price of HFCVs falling to the ICEV level was most effective in terms of the diffusion of HFCVs, followed by the reduction in fuel costs, the improvement in maximum drivable range, and the expansion of infrastructure for hydrogen charging stations. However, to find out the economic feasibility and efficiency considering the budget and consumers' welfare, we analyzed two scenarios assuming that the government supports discounts on fuel costs of HFCVs and the government aims to expand the charging infrastructure for HFCVs. As of 2030, the government need to spend about 2.46 million KRW to distribute one HFCV with supporting the fuel cost of hydrogen by 40 KRW/km, while the cost of distributing on HFCV was about 4.07 million KRW under the policy of expanding the infrastructure of the charging station to about 5 percent of the number of gas stations. Total required budget for each policy was 1.33 trillion KRW and 1.71 trillion KRW. Consumer surplus for expanding the charging stations of HFCVs to about 600 stations about 154 billion KRW. Therefore, in terms of the feasibility of the policy considering the welfare of consumers, the policy for expanding the infrastructure of hydrogen charging was not founded as feasible when considering the consumer welfare aspects.

This study analyzed the diffusion policy of HFCVs in diverse perspectives, reflecting consumers preferences. However, there is a limitation in this study that it considers hydrogen usage only in the vehicle sector, especially for the mid-size vehicles. We hope that future research will predict more widespread hydrogen usage by taking into account the entire transportation sector, such as trucks, buses, and commercial vehicles. Furthermore, we expect that many future empirical studies will be conducted considering the demand for hydrogen fuel for power generation, commerce, and residential sectors. Such studies would help establish hydrogen policies in a more realistic and diverse way for many countries.

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산업통상자원부 (2019). 수소 경제 활성화 로드맵

Appendix 1: Choice Experiment Survey

This paper utilized choice experiment survey results to examine the consumers' preferences on vehicle types. The survey was executed by a professional polling agency, Gallup Korea, during the second and third week of November year 2020. Two versions of questionnaires (A-type and B-type) with different choice sets were presented to two different samples from 455 total respondents. The A-type of survey questionnaires used for the choice experiment is appended for reference.

한국갤럽

08167 서울시 종로구 사직로 70 T 02-3702-2100 GALLUP
www.gallup.co.kr F 02-3702-2121 INTERNATIONAL

전력서비스에 대한 인식 및 태도 조사

GMR 2020-131-062

안녕하십니까?

이번에 한국갤럽조사연구소에서는 서울대학교의 의뢰로 '수소연료전지자동차에 대한 인식 및 태도 조사'를 실시하고 있습니다. 본 조사는 **전력서비스에 대한 일반국민 여러분의 인식 및 의견을 여쭙는 조사입니다.**
본 질문에는 맞고 틀리는 답이 없으며, 이런 의견을 갖고 있는 사람이 몇 퍼센트 (%)라는 식으로 통계를 내는 데에만 이용되며, 그 외의 목적에는 절대로 이용되지 않으니 평소 생각대로 응답해 주시면 됩니다. 또한, 귀하께서 응답해 주신 내용은 통계법 (제33조)에 따라 통계목적으로만 이용되며, 귀하의 의견은 철저히 보호됨을 약속드립니다. 바쁘시겠지만, 조사에 협조해 주시면 대단히 감사드리겠습니다.

2020년 11월
한국갤럽조사연구소

먼저, 응답자 선정 질문입니다.

SQ1. 귀하의 성별은 어떻게 됩니까?

1. 남자
2. 여자

SQ2. 귀하의 나이는 올 해 만으로 어떻게 되십니까?

만 ☐☐ 세 → **만19-68세까지만 조사할 것**

SQ3. 귀하께서 현재 거주하고 계시는 지역은 어디입니까?

1. 서울	2. 부산	3. 대구	4. 인천
5. 광주	6. 대전	7. 울산	8. 세종
9. 경기도	10. 강원도	11. 충청북도	12. 충청남도
13. 전라북도	14. 전라남도	15. 경상북도	16. 경상남도
17. 제주도	18. 외국에 거주한다 → **조사종료**		

아래에 명시된 질문 응답시 주의사항을 숙지하신 후, 질문에 응답해 주십시오.

질문 응답시 주의사항

1. 질문지는 맨 앞 페이지부터 순서대로 응답해 주십시오. 특별한 언급이 없다면, 모든 질문에 빠짐없이 응답해 주시기 바랍니다.
2. 질문에 응답하시기 전에 질문 앞에 제시된 설명문을 잘 읽고, 숙지하신 후 응답해 주시기 바랍니다.
3. 질문은 주관식과 객관식으로 구성되어 있습니다. 주관식 질문 응답은 응답란에 직접 적어주시고, 객관식 질문은 제시된 보기 번호에 ○표 해 주시기 바랍니다. 또한, 질문 항목별로 특별한 언급이 없는 한 가장 최근을 기준으로 응답해 주시면 됩니다.

D. 친환경 자동차 선호도

D-1. 자동차 보유 현황 및 운전 행동 파악

Da1. (전체 응답자 대상)
현재 귀하나 귀댁에서는 자동차를 보유하고 있습니까?

1. 예 (있다)
2. 아니오 (없다) → **Da2.로 가십시오**

Da1-1. (Da1.에서 1. 예(있다)에 응답한 경우만 응답해 주십시오)
현재 보유 차량과 이전 차량의 구매 시점은 언제입니까?

구분	현재 보유 차량	이전 구매 차량
구매시점	□□□□ 년	□□□□ 년 0. 이전 구매차량 없음.

Da1-1-1. (Da1.에서 1. 예(있다)에 응답한 경우만 응답해 주십시오)
그럼, 귀댁에서는 자동차를 모두 몇 대나 보유하고 있습니까?

□ 대

Da1-2. (Da1.에서 1. 예(있다)에 응답한 경우만 제시, Da1-1-1.에서 2대 이상 응답 시에만 부사용 자동차 응답란 제시)
현재 귀댁에서 보유하고 있는 자동차의 사양을 응답해 주십시오.

항목		주이용 자동차 (자동차를 보유한 응답자 모두 응답)	부이용 자동차 (자동차를 2대 이상 보유한 경우만 응답)
1. 제조년도		□□□□ 년	□□□□ 년
2. 국산차/수입차 여부		① 국산차 ② 수입차	① 국산차 ② 수입차
3. 자동차 모델명 (구체적으로 응답해 주십시오.)		□	□
4. 차종		① 경차 ② 소형차 ③ 준중형차 ④ 중형차 ⑤ 대형차 ⑥ SUV/RV	① 경차 ② 소형차 ③ 준중형차 ④ 중형차 ⑤ 대형차 ⑥ SUV/RV
5. 유종		① 휘발유 ② 경유 ③ LPG ④ 하이브리드 ⑤ 전기 ⑥ 수소	① 휘발유 ② 경유 ③ LPG ④ 하이브리드 ⑤ 전기 ⑥ 수소
6. 신차/중고차 구입 여부		① 신차 ② 중고차	① 신차 ② 중고차
7. 구입가격 (단위 : 백만원)		□□ 천 □ 백	□□ 천 □ 백
8. 1리터당 주행거리(연비) [전기차는 kWh당, 수소차는 kg당]		□□ km	□□ km
9. 연평균 주행거리		□□ 만 □ 천km	□□ 만 □ 천km
10. 일주일 평균 주행거리		□□□ km	□□□ km
일주일 평균 주행거리 중 용도별 주행거리의 비중을 10-1 ~ 10-5에 응답해 주시기 바랍니다.			
용도별 주행거리의 비중	10-1. 출퇴근용	□□□ %	□□□ %
	10-2. 사업용/업무용	□□□ %	□□□ %
	10-3. 레저 및 장거리 여행용	□□□ %	□□□ %
	10-4. 가정/일상 생활용(쇼핑 등)	□□□ %	□□□ %
	10-5. 기타	□□□ %	□□□ %
	합계	1 0 0 %	1 0 0 %

Da1-3. (부이용 자동차를 보유한 응답자만 응답해주십시오.)
귀하께서는 추후 차량을 교체하신다면 어떤 차량을 교체하시겠습니까?

1. 주이용 자동차
2. 부이용 자동차

Da2. (전체 응답자 대상)
귀하께서는 아래의 수송부문 에너지/환경 관리 정책에 대해 얼마나 알고 계십니까?

	전혀 모른다	모르는 편이다	보통이다	아는 편이다	매우 잘 안다
	1	2	3	4	5
1. 자동차 운행으로 인한 외부 비용(환경오염비용, 혼잡비용)의 개념	1	2	3	4	5
2. 자동차 운행에 따른 온실가스(CO_2) 배출량	1	2	3	4	5
3. 자동차 운행에 따른 미세먼지 배출량	1	2	3	4	5
4. 유류비 내 세금 구성 항목	1	2	3	4	5
5. 유류비 내 세금 비중	1	2	3	4	5
6. 자동차 평균에너지소비효율제도 (평균연비제도)	1	2	3	4	5
7. 전기차 및 수소차에 대한 정부 보조금	1	2	3	4	5

Da3. (전체 응답자 대상)
귀하께서 자동차를 구매하실 때, 중요하게 생각하는 속성은 무엇입니까?
중요하다고 생각하시는 순위대로 5위까지 응답해 주십시오.

1위 응답란		2위 응답란		3위 응답란		4위 응답란		5위 응답란	

1. 차량가격(소비세 포함)
2. 자동차종류(승용, SUV 등)
3. 차량엔진크기(1,000cc 등)
4. 연비(1리터당 주행거리)
5. 유지비(연료가격, 세금, 유지보수비)
6. 차량브랜드(현대, BMW 등)
7. 친환경성(온실가스/미세먼지 배출량)
8. 충전인프라(개수, 접근성)
9. 충전시간
10. 자동차 디자인(외형)
11. 자동차 안전성
12. 정부 혜택(보조금, 세금감면)
13. 1회 충전 시 주행 최대 가능거리

D-2. 자동차 유형별 선호도

1. 먼저 친환경 자동차(전기차, 수소차)를 포함하여 신차 구입에 대한 유형별 선호도에 대한 질문입니다.
2. 응답하실 유형별 선호도 질문은 2,000CC 수준의 중형 세단 자동차의 여러 속성과 속성 및 수준 설명문과 자동차 유형별 선호도 (① 선호 순위 응답란, ② 구매의향 자동차) 를 묻는 질문 5개가 제시됩니다.
3. 귀하께서는 ① 아래 적혀있는 자동차의 여러 속성과 속성별 수준에 대한 설명문을 숙지하시고, ② 제시된 자동차 유형 중 선호 순위 (1위~4위)와 비선택이 포함되지 않은 4가지 자동차 유형 중 가장 구매의향 높은 자동차(단답), 4가지 자동차 유형 중 구매의향 높은 자동차 유형(중복응답), 비선택을 포함한 5가지 자동차 유형별 예정 주행거리 비율을 응답해 주시면 됩니다.

<table>
<tr><th colspan="2">속성</th><th>속성 설명 및 수준</th></tr>
<tr><td>1. 자동차 연료 및 구동 방식</td><td>수준
(3개)</td><td>① 내연기관차 (휘발유경유) : 가솔린엔진과 휘발유(가솔린)를 사용하는 가솔린 자동차, 디젤엔진과 경유(디젤)를 사용하는 디젤 자동차를 모두 포함하는 내연기관 자동차를 지칭함. 화석연료를 이용하여 엔진을 구동하기에, 매연(유해물질) 및 각종 미세먼지가 배출됨.
② 전기차 (전기충전) : 전기를 동력으로 운행하는 자동차로, 배터리에 축적된 전기를 바탕으로 엔진을 구동하는 자동차를 지칭함. 운행 중에 매연 및 각종 미세먼지가 배출되지 않음.
③ 수소차 (수소연료) : 산소와 수소의 전기화학 반응을 통해서 얻은 전기를 동력으로 활용하는 자동차를 지칭함. 운행 중에 물만 배출하고 매연 및 각종 미세먼지가 배출되지 않음.</td></tr>
<tr><td rowspan="2">1.1 전기차 충전에 사용되는 전력 발전원 비중 (전기차에만 해당)</td><td>설명</td><td>1) 전기차는 현재 국내 발전믹스(발전원 구성)에서 전기를 공급 받거나 또는 변화된 발전믹스에서 전기를 공급받을 수 있다고 가정한다.
2) 전력생산 방식은 사용하는 에너지원에 따라 크게 화력, 원자력, 신재생에너지 발전으로 나눌 수 있으며, 국내 에너지원별 발전비중은 석탄 40%, 액화천연가스(LNG) 25%, 원자력 30%, 신재생 2%, 기타 3%임.
3) 에너지원별 주요 장점과 단점은 아래와 같음.
<table>
<tr><th></th><th>화력(석탄) 발전</th><th>원자력 발전</th><th>천연가스(LNG) 발전</th><th>신재생에너지 발전</th></tr>
<tr><td>장점</td><td colspan="2">① 대규모 발전이 가능하고 발전단가가 저렴함
② 연료공급이 안정적</td><td>① 발전효율이 높음
② 경제성과 환경성 측면은 신재생과 화력·원자력 중간</td><td>① 환경 친화적 (태양광, 풍력 등 이용)</td></tr>
<tr><td>단점</td><td>① 온실가스 및 미세먼지 발생
② 대부분 연료를 수입에 의존</td><td>① 방사능 유출 피해 우려
② 방사성 폐기물 발생</td><td>① 가스 운송 및 보관 비용이 비쌈
② 대부분 연료를 수입에 의존</td><td>① 발전단가가 비쌈 (전기요금 상승 가능성)
② 전력공급의 안정성 낮음</td></tr>
</table></td></tr>
<tr><td>수준
(3개)</td><td>① 현재 국내 에너지원별 발전량 비중 유지 : 화력 40%, 가스 25%, 원자력 25%, 신재생 06%, 기타 4%
② 현재 대비 원자력 비중 대폭 감소 (천연가스 증가) : 화력 40%, 가스 40%, <u>원자력 10%</u>, 신재생 6%, 기타 4%
③ 현재 대비 신재생 비중 대폭 증가 (화력, 원자력 감소) : 화력 25%, 가스 21%, 원자력 20%, <u>신재생 30%</u>, 기타 4%</td></tr>
<tr><td rowspan="2">1.2 수소연료 생산에 사용되는 연료 생산 방식 비중 (수소차에만 해당)</td><td>설명</td><td>1) 현재 국내 수소 생산량의 약 90%는 부생수소 방식으로 충당하고 있음.
2) 그러나 수소의 수요가 늘어나게 되면 부족한 수소 공급량은 천연가스 개질 방식과 전기분해 방식으로 충당해야하는 상황
3) 수소생산 방식별 주요 장점과 단점은 아래와 같음.
<table>
<tr><th></th><th>부생수소</th><th>천연가스 개질 방식의 수소 생산</th><th>신재생에너지를 이용한 전기분해 방식의 수소 생산</th></tr>
<tr><td>설명</td><td>석유 정제 공정 과정에서 부수적으로 발생</td><td>천연가스를 고온·고압의 수증기로 분해하여 생산</td><td>전기를 물에 가하여 수소와 산소로 분해하여 생산 (신재생에너지 활용)</td></tr>
<tr><td>장점</td><td>① 폐가스를 활용하여 생산 단가가 낮음
② 석유 정제 공정 과정 외 추가적 온실가스 배출 없음</td><td>① 대량생산 가능
② 생산원가는 부생수소보다는 높고 수전해질수소보다는 낮음
③ 안정된 기술</td><td>① 환경친화적(CO_2 미발생)
② 다양한 에너지원 활용 가능</td></tr>
<tr><td>단점</td><td>① 생산량이 제한적
② 정제과정이 필요함</td><td>① 화석연료를 이용하기에 온실가스가 다량 발생함
② 에너지 안보 취약</td><td>① 높은 생산단가
② 대량생산이 불가능
③ 낮은 에너지효율성</td></tr>
</table></td></tr>
<tr><td>수준
(2개)</td><td>부생수소로 생산하는 방식 외에 나머지 수소생산방식에 대한 믹스를 묻는 질문임
① 천연가스 개질 방식의 수소 생산 중심 :천연가스 개질 방식: 70%, 신재생에너지 전기분해: 30%
② 신재생에너지를 이용한 전기분해 방식의 수소 생산 중심 :천연가스 개질 방식: : 30%, 신재생에너지 전기분해: 70%</td></tr>
</table>

속성		속성 설명 및 수준
2. 주유·충전 시간 (분)	설명	1회 주유 및 (급속)충전 시 걸리는 총 시간을 의미함
	수준 (4개)	① 5분 ② 20분 ③ 40분 ④ 60분
3. 연료비용 (원/km)	설명	연료비용은 1Km 주행 시 드는 비용(원)임 예를 들어, 휘발유 가격이 1350원/리터이고 휘발유차 연비가 10km/리터이면, 연료비용은 1km 주행에 135원 필요
	수준 (4개)	① 25원/km (32,500원/월) ② 50원/km (65,000원/월) ③ 100원/km (130,000원/월) ④ 150원/km (195,000원/월)
4. 주유·충전 접근성 (%)	설명	현재 이용 가능한 전체 주유소 수 대비, 해당 차량의 주유/충전이 가능한 주유/충전소의 비율
	수준 (3개)	① 100% (전체 주유소 수에 비해 100% 수준) ② 50% (전체 주유소 수에 비해 50% 수준) ③ 10% (전체 주유소 수에 비해 10% 수준)
5. 최대주행가능거리 (km)	설명	1회 완전 주유/충전 시 운행할 수 있는 최대 주행 가능 거리를 의미함 (서울-부산 편도 약400km)
	수준 (4개)	① 400km ② 600km ③ 800km ④ 1,000km
6. 차량 가격 (만원)	설명	차량 등록세, 취득세를 제외한 차량 구매가격만을 의미함
	수준 (4개)	① 2,000만원 ② 3,500만원 ③ 5,000만원 ④ 6,500만원

☞ 링크 수정 : 응답자를 두 그룹으로 나누어서 절반은 타입A, 절반은 타입B로 제시할 것

타입 A

Db1. 다음 제시된 자동차 유형에 대해 귀하의 선호도와 구매의향 자동차를 응답해 주십시오.

	▣ 중형 자동차 선호도 질문 1	자동차 A	자동차 B	자동차 C	자동차 D	자동차 E
자동차 속성	1. 연료 형태	내연기관 자동차	전기차	전기차	수소차	현재 차량 이용
	전기차 또는 수소차 에너지원 구성		현재 국내 에너지원별 발전량 비중 유지 (석탄40%, 가스25%, 원자력 25%, 신재생6%)	현재 대비 원자력 비중 대폭 감소 (석탄40%, 가스40%, 원자력 10%, 신재생6%)	천연가스를 이용한 개질 방식 중심 (개질방식 70%, 전기분해 30%)	
	2. 주유·충전 시간	60분	60분	5분	40분	
	3. 연료비용	25원/km	100원/km	50원/km	150원/km	
	4. 주유 및 충전 접근성	100%(전체 주유소 대비 100% 수준)	10%(전체 주유소 대비 10% 수준)	50%(전체 주유소 대비 50% 수준)	50%(전체 주유소 대비 50% 수준)	
	5. 최대주행가능거리	600km	800km	600km	400km	
	6. 차량 가격	3,500만원	5,000만원	2,000만원	6,500만원	
① 선호 순위		☐ 위	☐ 위	☐ 위	☐ 위	
② 구매의향 자동차 1개 응답란		유형 A	유형 B	유형 C	유형 D	
③ 구매의향 자동차 복수 응답란		유형 A	유형 B	유형 C	유형 D	
④ 예정주행거리 비율 (%) (합이 100이 되도록 응답)						

	▣ 중형 자동차 선호도 질문 2	자동차 A	자동차 B	자동차 C	자동차 D	자동차 E
자동차 속성	1. 연료 형태	내연기관 자동차	내연기관 자동차	전기차	수소차	현재 차량 이용
	전기차 또는 수소차 에너지원 구성			현재 대비 신재생에너지 비중 대폭 증가 (석탄25%, 가스21%, 원자력20%, 신재생30%)	천연가스를 이용한 개질 방식 중심 (개질방식 70%, 전기분해 30%)	
	2. 주유·충전 시간	40분	5분	20분	60분	
	3. 연료비용	100원/km	150원/km	150원/km	25원/km	
	4. 주유 및 충전 접근성	10%(전체 주유소 대비 10% 수준)	50%(전체 주유소 대비 50% 수준)	10%(전체 주유소 대비 10% 수준)	100%(전체 주유소 대비 100% 수준)	
	5. 최대주행가능거리	600km	800km	1,000km	1,000km	
	6. 차량 가격	2,000만원	5,000만원	3,500만원	2,000만원	
① 선호 순위		☐ 위	☐ 위	☐ 위	☐ 위	
② 구매의향 자동차 1개 응답란		유형 A	유형 B	유형 C	유형 D	
③ 구매의향 자동차 복수 응답란		유형 A	유형 B	유형 C	유형 D	
④ 예정주행거리 비율 (%) (합이 100이 되도록 응답)						

	■ 중형 자동차 선호도 질문 3	자동차 A	자동차 B	자동차 C	자동차 D	자동차 E
자동차 속성	1. 연료 형태	내연기관 자동차	전기차	전기차	수소차	현재 차량 이용
	전기차 또는 수소차 에너지원 구성		현재 대비 신재생에너지 비중 대폭 증가 (석탄25%, 가스21%, 원자력20%, 신재생30%)	현재 국내 에너지원별 발전량 비중 유지 (석탄40%, 가스25%, 원자력 25%, 신재생6%)	신재생에너지를 이용한 전기분해 방식 중심 (개질방식 30%, 전기분해 70%)	
	2. 주유·충전 시간	20분	60분	20분	40분	
	3. 연료비용	150원/km	150원/km	25원/km	50원/km	
	4. 주유 및 충전 접근성	100%(전체 주유소 대비 100% 수준)	10%(전체 주유소 대비 10% 수준)	50%(전체 주유소 대비 50% 수준)	100%(전체 주유소 대비 100% 수준)	
	5. 최대주행가능거리	400km	1,000km	400km	1,000km	
	6. 차량 가격	6,500만원	2,000만원	2,000만원	5,000만원	
① 선호 순위		☐ 위	☐ 위	☐ 위	☐ 위	
② 구매의향 자동차 1개 응답란		유형 A	유형 B	유형 C	유형 D	
③ 구매의향 자동차 복수 응답란		유형 A	유형 B	유형 C	유형 D	
④ 예정주행거리 비율 (%) (합이 100이 되도록 응답)						

	■ 중형 자동차 선호도 질문 4	자동차 A	자동차 B	자동차 C	자동차 D	자동차 E
자동차 속성	1. 연료 형태	내연기관 자동차	내연기관 자동차	전기차	수소차	현재 차량 이용
	전기차 또는 수소차 에너지원 구성			현재 대비 원자력 비중 대폭 감소 (석탄40%, 가스40%, 원자력 10%, 신재생6%)	신재생에너지를 이용한 전기분해 방식 중심 (개질방식 30%, 전기분해 70%)	
	2. 주유·충전 시간	5분	60분	40분	5분	
	3. 연료비용	25원/km	50원/km	25원/km	150원/km	
	4. 주유 및 충전 접근성	50%(전체 주유소 대비 50% 수준)	50%(전체 주유소 대비 50% 수준)	10%(전체 주유소 대비 10% 수준)	100%(전체 주유소 대비 100% 수준)	
	5. 최대주행가능거리	1,000km	800km	800km	800km	
	6. 차량 가격	5,000만원	3,500만원	6,500만원	2,000만원	
① 선호 순위		☐ 위	☐ 위	☐ 위	☐ 위	
② 구매의향 자동차 1개 응답란		유형 A	유형 B	유형 C	유형 D	
③ 구매의향 자동차 복수 응답란		유형 A	유형 B	유형 C	유형 D	
④ 예정주행거리 비율 (%) (합이 100이 되도록 응답)						

G. 응답자 특성 (자료분류용 질문)

G1. (전체 응답자 대상)
실례지만, 귀하의 교육 수준에 해당하는 학년 번호에 응답해 주십시오.

	초등학교						중학교			고등학교			대학교				대학원			
0 (무학)	1 (1학년)	2 (2학년)	3 (3학년)	4 (4학년)	5 (5학년)	6 (6학년)	7 (1학년)	8 (2학년)	9 (3학년)	10 (1학년)	11 (2학년)	12 (3학년)	13 (1학년)	14 (2학년)	15 (3학년)	16 (4학년)	17 (1년차)	18 (2년차)	19 (3년차)	20 (4년차 이상)

G2. (전체 응답자 대상)
귀하의 직업은 무엇입니까?

1. 자영업(종업원 9명 이하 소규모 업소 주인/가족종사자)
2. 판매/서비스직(상점점원, 세일즈맨 등)
3. 기능/숙련공(운전사, 선반/목공, 숙련공 등)
4. 일반작업직(토목 현장작업/청소/수위/육체노동 등)
5. 사무/기술직(일반회사 사무직/기술직, 교사 등)
6. 경영/관리직(5급 이상 공무원/기업체 부장 이상 등)
7. 전문/자유직(대학교수/의사/변호사/예술가/종교인 등)
8. 전업주부
9. 학생
10. 무직
11. 기타(구체적으로 응답해 주십시오 : ________________)

G3. (전체 응답자 대상)
귀하는 세대주입니까?

1. 예(세대주임)
2. 아니오(세대주 아님)

G4. (전체 응답자 대상)
① 현재 귀하와 **함께 살고 계신 가족은 모두 몇 명입니까? 응답자 본인을 포함한 가족 수를** 응답해 주십시오.
② 그럼 귀하와 함께 살고 계신 가족 중, 만 **60**세 이상, **초중고생**, **미취학** 아동과 그 외 가족은 각각 몇 명이나 됩니까?

구분		응답란
① 같이 살고 있는 가족 수 (응답자 본인 포함)		☐ 명
② 같이 살고 있는 가족구성 (합계가 ①과 같음)	- 응답자 본인	1 명
	- 만 60세 이상 가족 수	☐ 명
	- 초중고생 가족 수	☐ 명
	- 미취학 아동 가족 수	☐ 명
	- 그 외 가족 수	☐ 명

G5. (전체 응답자 대상)
귀댁에서 소득이 있는 가구원은 총 몇 명입니까?
☞ G4의 ① 같이 살고 있는 가족 수 이하의 숫자만 응답 가능하도록 설정

[   ] 명

G6. (전체 응답자 대상)
현재 귀댁의 월평균 소득 수준은 얼마나 됩니까? 세금은 제외하며 보너스, 이자수입 등 모든 수입을 합해서 응답해 주십시오.

1. 99만원 이하
2. 100만원~149만원 이하
3. 150만원~199만원 이하
4. 200만원~249만원 이하
5. 250만원~299만원 이하
6. 300만원~399만원 이하
7. 400만원~499만원 이하
8. 500만원~699만원 이하
9. 700만원~999만원 이하
10. 1,000만원 이상

G6-1. (전체 응답자 대상)
현재 귀댁의 월평균 소득 수준은 구체적으로 얼마입니까?
☞ G6.의 응답범위 내의 금액만 응답 가능하도록 설정

월 평균 소득수준 : [   ] 천 [   ] 백 [   ] 십 [   ] 만원 정도

G7. (전체 응답자 대상)
현재 귀댁의 월평균 지출 수준은 얼마나 됩니까? 보너스, 저축은 제외한 순수한 지출 수준을 응답해 주십시오.

1. 49만원 이하
2. 50만원~99만원 이하
3. 100만원~149만원 이하
4. 150만원~199만원 이하
5. 200만원~249만원 이하
6. 250만원~299만원 이하
7. 300만원~349만원 이하
8. 350만원~399만원 이하
9. 400만원~499만원 이하
10. 500만원 이상

G7-1. (전체 응답자 대상)
현재 귀댁의 월평균 지출 수준은 구체적으로 얼마입니까?
☞ G7의 응답범위 내의 금액만 응답 가능하도록 설정

월 평균 지출수준 : [   ] 천 [   ] 백 [   ] 십 [   ] 만원 정도

끝까지 조사에 협조해 주셔서 감사합니다.

Abstract (Korean)

전 지구적 기후변화가 날로 심각해지는 가운데 수송 부문에서는 기존 내연기관 자동차 시대에서 대체연료 자동차 시대로의 전환이 가까워지고 있다. 대체연료 자동차 가운데 수소연료전지차는 전기차와 함께 친환경성으로 인하여 미래 자동차 시장의 판도를 바꿀 차세대 차량으로 평가되고 있다. 그러나 대체연료자동차의 친환경성에 대해 말하기 위해서는 연료 생산 공정에서 까지의 환경성을 평가할 필요가 있다. 이러한 측면에서 본 연구는 수소연료전지차의 확산에 따른 환경적 영향을 분석하기 위해 전기차의 발전믹스와 수소연료전지차의 수소생산 믹스를 고려하여 소비자 선호도를 분석해서 미래의 자동차 시장을 예측하고자 한다. 본 연구에서 혼합 로짓 모형을 이용하여 소비자 선호도를 분석한 결과, 전기차의 경우 신재생 에너지 중심 발전 믹스 하에 생산된 전력에 의해 운행되는 전기차, 현재 발전 믹스에 하에 생산된 전력에 의해 운행되는 전기차 순으로 선호하는 것으로 나타났으며 원자력 발전 비중이 현재 수준에 비해 많이 감소된 전력 믹스에 의해 생산된 전력에 의해 사용되는 전기차는 현재 발전 믹스를 이용하는 경우와 소비자 선호에 있어서 큰 차이가 없는 것으로 나타났다. 수소연료전지차의 경우 소비자들에게 있어서 전기분해공정(수전해질 수소) 위주의 믹스로 생산되는 수소에 의해 구동되는 수소연료전지차와 천연가스 개질 공정 (개질수소) 위주의 믹스로 생산되는 수소에 의해 구동되는 수소연료전지차는 그 생산믹스 간의 선호의 차이가 없는 것으로 나타났다. 본 연구는 이러한 추정 결과를 바탕으로 2030년 기준 수소 생산 믹

스에 따른 미래 온실가스 배출량을 예측하기 위해 시나리오 분석을 실시했다. 개질 수소 중심의 수소 생산 믹스 위주의 수소차 확산에 따른 환경적 영향은 수전해질 수소 중심의 수소 생산 믹스 위주의 수소차 환삭에 따른 환경적 영향에 비해 약 2배 차이가 나타나는 것으로 추정되었다. 이러한 분석 결과는 향후 여러 국가에서 수소 경제를 활성화하기 위한 정책 수립에 필요한 함의가 될 것이라 기대한다.

주요어: 대체연료자동차, 전과정분석, 온실가스배출량, 이산선택실험, 혼합로짓 모형, 환경성평가

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