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Preference Structure on the Design of Hydrogen Refueling Stations to Activate Energy Transition

Soyeong Park [1], Solji Nam [1], Myoungjin Oh [1], Ie-jung Choi [2] and Jungwoo Shin [1,*]

[1] Department of Industrial and Management Systems Engineering, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin, Gyeonggi 17104, Korea; sysy@khu.ac.kr (S.P.); sjnam@khu.ac.kr (S.N.); bristo94@khu.ac.kr (M.O.)

[2] Center of Public R&D Program Evaluation, Science and Technology Policy Institute (STEPI), A-3F Sejong National Research Complex, 370 Sicheong-daero, Sejong-si 30147, Korea; matthew@stepi.re.kr

* Correspondence: shinjung11@khu.ac.kr; Tel.: +82-31-201-3687; Fax: +82-31-204-8114

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Abstract: As a countermeasure to the greenhouse gas problem, the world is focusing on alternative fuel vehicles (AFVs). The most prominent alternatives are battery electric vehicles (BEV) and fuel cell electric vehicles (FCEVs). This study examines FCEVs, especially considering hydrogen refueling stations to fill the gap in the research. Many studies suggest the important impact that infrastructure has on the diffusion of AFVs, but they do not provide quantitative preferences for the design of hydrogen refueling stations. This study analyzes and presents a consumer preference structure for hydrogen refueling stations, considering the production method, distance, probability of failure to refuel, number of dispensers, and fuel costs as core attributes. For the analysis, stated preference data are applied to choice experiments, and mixed logit is used for the estimation. Results indicate that the supply stability of hydrogen refueling stations is the second most important attribute following fuel price. Consumers are willing to pay more for green hydrogen compared to gray hydrogen, which is hydrogen produced by fossil fuels. Driver fuel type and perception of hydrogen energy influence structure preference. Our results suggest a specific design for hydrogen refueling stations based on the characteristics of user groups.

Keywords: alternative fuel vehicle; consumer preference; energy transition; fuel cell vehicle; hydrogen refueling station; mixed logit; vehicle infrastructure

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1. Introduction

Due to greenhouse gas emissions (GHG), 195 countries have signed the Paris Agreement. Among industries, the transportation sector is responsible for 24% of global carbon dioxide (CO_2) emissions [1]. Early car manufacturers tried to solve this problem by improving energy efficiencies [2], but the fundamental problem is not solved yet. Therefore, zero emission automobile research has been conducted [2]. Among zero emission automobiles, battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEV) are most frequently mentioned [3]. Car manufacturers are gradually increasing the focus on developing environmentally friendly alternative fuel vehicles (AFVs) in coordination with countries' popularization plans [2]. For BEVs, General Motors began development in the 1990s, and many manufacturers, including Tesla, are now developing BEVs. The BEV inventory has grown quickly, surpassing five million units in 2018 [4]. However, the FCEV inventory was only 11,200 units in 2018 [5], indicating insufficient popularity and related research compared to BEV. The dominant type of alternative energy vehicle for the future is being discussed. Although FCEVs are growing at a slower pace than BEVs, they may have advantages in travelable miles on a full charge [6] and reducing refueling time [7]. Due to the reasons mentioned above, this study examines FCEVs as zero emission alternatives.

Similar to BEVs, FCEVs also use an all-electric power train, but the energy source is a fuel cell stack. An FCEV uses hydrogen as fuel and releases water and heat [8]. As FCEVs use a new energy source, hydrogen, it is important to expand infrastructure for the successful diffusion of FCEVs. The use of eco-friendly cars cannot increase without improvement in the infrastructure [9]. A refueling station supplies hydrogen for FCEVs. At the end of 2019, 470 hydrogen refueling stations were in operation worldwide [10]. Japan had the most stations, with 113, followed by Germany with 81 and the United States with 64, and 34 stations were in operation in South Korea [10]. All hydrogen refueling stations in South Korea are provided with gray hydrogen [11], and the government is planning to increase the supply with green hydrogen [12].

Previous studies analyzed the influence of infrastructure and hydrogen refueling stations on the diffusion of FCEVs. The geographical distribution of hydrogen refueling stations is generally consistent with the number of FCEVs [13]. Many studies concentrated on the effects of subsidies, policy support, and initial infrastructure construction related to the technical adoption of FCEVs [14,15]. However, these studies did not consider the future direction of the design of new hydrogen refueling stations. Previous studies only considered the relationship between AFVs and infrastructure, and infrastructure was assumed to be one variable, such as level of accessibility. Through these studies, only the diffusion index of hydrogen refueling stations can be presented, and the implications for the direction of the infrastructure's supplementary configuration cannot be derived.

Considering hydrogen refueling stations, some consumers indicate that hydrogen production is highly dependent on fossil fuels [16], countering the slogan of decarbonization [17]. Additionally, the anxiety of consumers about hydrogen explosions hinders the diffusion of products [18], and the storage and transportability of hydrogen is also known as a bottleneck [19]. Thus, there are various external factors related to hydrogen refueling stations, but no research has been conducted on how to construct them with consideration of infrastructure attributes. Therefore, this study analyzes the structure of a preferred hydrogen refueling station, which includes structure properties such as hydrogen production methods, accessibility to infrastructure, transportation, and storage [19,20].

The main purpose of this study is to analyze the structure of consumer preference for hydrogen refueling stations and it suggests future infrastructure dissemination plans in order to help active energy transition. Previous studies have set out to discuss the infrastructure that should be established for the dissemination of alternative fuel vehicles [21]. There was also a need to construct a hydrogen refueling station for the diffusion of FCEVs [13,22]. However, there was not enough discussion on the design or the specific aspects of the hydrogen refueling station. South Korea plans to expand production of hydrogen vehicles from 2000 in 2018 to 6.2 million in 2040 (2.9 million for domestic demand and 3.3 million for exports) and to expand hydrogen refueling stations from 14 in 2018 to 310 in 2022 and 1200 in 2040 [12]. These schemes represent the government's willingness to disseminate FCEVs. Additionally, South Korea holds various automobile manufacturing technologies, and Hyundai, South Korea's largest automaker, has invested heavily in FCEVs and previously launched commercial FCEVs [23]. In consideration of this, it is relevant to assume that Korean consumers likely know more about FCEVs and are suitable as the research target [24]. Therefore, we analyze the consumer preference structure for the design of hydrogen charging stations in South Korea, considering the demand side. In particular, a mixed logit model was used to reflect the heterogeneity of consumers. In addition, scenario analysis was performed based on preference analysis.

This paper is organized as follows. Section 2 investigates previous studies on AFV and infrastructure, including FCEV. Section 3 describes the methodology used, and Section 4 describes the data for the experiment. Section 5 explains the analysis results and scenario analysis results for a hydrogen fueling station, and Section 6 concludes and outlines policy implications.

2. Literature Review

Previous studies obtained quantitative information on consumer preferences to expand various eco-friendly AFV markets. Governments worldwide (the United States, Japan, the Netherlands, Canada, and France) are establishing policies to promote the expansion of the eco-friendly AFV market [25]. In Korea, vehicle users have experienced the impacts of oil price changes, which has led to increased interest in eco-friendly AFV vehicles. Additionally, several empirical studies on vehicles and infrastructure analyzed the impact of infrastructure on the adoption of AFVs [26]. The AFV automobile market and infrastructure market spread were proposed simultaneously, as electric cars could be constrained by diving range without charging infrastructures, and fuel storage and hydrogen car infrastructure were barriers to the widespread introduction of hydrogen cars [27,28]. An agent-based model was used to simulate the co-expansion of plug-in electric vehicles (PEVs) and PEV infrastructure [21]. Low-speed charging cannot secure the economies of scale of charging costs by 2030, even if PEVs are increased, suggesting that deficient PEV infrastructure hinders the growth of PEVs.

Some studies have focused on FCEVs. FCEVs will increase in demand from 2030 to 2050, but there are problems to be solved, including fuel efficiency, mileage, and hydrogen refueling stations. Specifically, studies have mentioned that the expansion of hydrogen refueling stations is essential for the commercialization of hydrogen vehicles [29–31]. Lack of infrastructure, including battery refueling stations, high battery costs, and short mileage, requires high acceptance among vehicle consumers for mass market generation, and if infrastructure is improved, consumers are willing to pay higher prices for vehicle properties [22,32]. A study on the spread of hydrogen refueling stations for FCEV distribution, including determining the initial number of hydrogen refueling stations for self-sustaining market deflation through threefold simulation approach studies, was conducted [14]. Some studies suggested that households are willing to bear financial burdens, while others indicated positive attitudes about hydrogen refueling station policy [33]. To expand the supply of FCEVs, the South Korean government is overcoming these shortfalls through various policy measures, including financial support for purchasing hydrogen cars, tax cuts, and hydrogen refueling station installations [25]. In particular, refueling infrastructure impacts the growth of FCEVs, and research shows that the amount of FCEV supply is consistent with the geographical distribution of hydrogen filling stations. Therefore, countries like Korea are trying to build infrastructure for EVs and FCEVs and provide policy support [9].

However, most studies only highlight the need for hydrogen stations for FCEVs and do not show the characteristics necessary for hydrogen stations. Firstly, hydrogen stations face economic problems. Hydrogen refueling stations are predicted to operate under financial losses for about 10 to 15 years in the initial stage due to lack of demand for charging [34]. Therefore, reducing investment and operating costs and increasing utilization rates are essential, and economic analysis of how to invest in public resources is needed. The supply stability of hydrogen refueling stations will be a problem in the future [19]. Currently, hydrogen refueling stations can accommodate 25 FCEVs per day. Furthermore, FCEV stands for eco-friendly vehicles because no emissions are generated while driving; hydrogen energy production uses fossil fuels [17]. Many studies have shown that environmental concerns affect consumer consumption [35–37]. The expansion of hydrogen refueling stations is an essential factor in the supply of FCEVs, but it suffers from safety problems [38]. There are claims that hydrogen stations risk exploding [18]. Additionally, the perception of FCEVs can be negative, because it is difficult to install a large amount of fuel supply infrastructure practically [39]. However, there are no studies that comprehensively and quantitatively analyze these issues. This study intends to analyze the consumer preference structure for FCEV-related charging infrastructure, including the issues mentioned above, from an econometric perspective.

3. Methodology

The hydrogen fueling station has a variety of policy issues. Considering these in order to maximize consumer welfare, it is necessary to understand the structure of consumer preferences. Accordingly, this study uses a discrete selection model based on a random utility theory that analyzes consumer utility for multiple attributes.

The most widely used discrete selection model is the logit model, which is expressed in closed form for easy calculation. However, due to the independence of irrelevant alternative (IIA) restrictions, results may not correspond to reality. Therefore, this study uses the mixed logit model that considers consumer heterogeneity and reduces the IIA restrictions. The mixed logit model relaxes IIA constraints by assuming distribution in coefficients of consumer preference, reflecting the heterogeneity of individuals, and it better reflects reality [40]. This model is widely used to predict and analyze new products [41]. For example, it is used in forecasting the media market, analyzing the implementation of new programs in public transportation, or the establishment of energy policy [42–45]. Equation (1) defines the utility function of the mixed logit model:

$$U_{njt} = V_{njt} + \varepsilon_{njt} = \beta_n' X_{njt} + \varepsilon_{njt} \tag{1}$$

U_{njt} is the utility of respondent n by selecting alternative j in the choice set t. Utility can be divided into the deterministic term, V_{njt}, and the stochastic term, ε_{njt}. β_n' is the coefficient of attributes and is assumed to be normal or log-normal distribution consisting of b and $\sum$.

Based on Equation (1), the probability that the consumer n selects alternative j from the alternative set t is expressed in Equation (2).

$$P_{njt}(\theta) = \Pr\left(V_{njt} - V_{nkt} > \varepsilon_{nkt} - \varepsilon_{njt},\ \forall k \neq j\right) = \int \prod_{t=1}^{T} \left[\frac{e^{\beta_n' X_{njt}}}{\sum_m e^{\beta_n' X_{njt}}} \right] f(\beta|\theta) d\beta \tag{2}$$

This study estimates mixed logit using maximum simulated likelihood (MSL). Regarding the likelihood function in Equation (2), it is difficult to find an analytical solution through the maximum likelihood estimation [40]. MSL is one of the simulation utilization methods used to solve this problem [46]. MSL estimates randomly by making draws β^r from $f(\beta|\theta)$ R times and then calculates the average choice probability. It is expressed as Equation (3).

$$SLL(\theta) = \sum_{n=1}^{N} \ln\left\{ \frac{1}{R} \sum_{r=1}^{R} \prod_{t=1}^{T} \left[\frac{e^{\beta_n' X_{njt}}}{\sum_m e^{\beta_n' X_{njt}}} \right] \right\} \tag{3}$$

The estimated β can be used to calculate the amount of marginal willingness-to-pay (MWTP) and relative importance (RI). MWTP refers to the amount of change in willingness-to-pay by respondents, as a characteristic increases or decreases by one unit and is based on the compensation value from a microeconomic perspective. Relative importance is represented as a ratio of the part worth for each attribute and indicates how much each attribute affects consumer choice. In this case, $part - worth_x$ is calculated by multiplying the difference between the maximum level and the minimum level of the property by a parameter. MWTP and RI are calculated using Equations (4) and (5).

$$MWTP_k = -\frac{\beta_k}{\beta_{price}} \tag{4}$$

$$RI_k = \frac{part - worth_k}{\sum_l part - worth_l} = \frac{\beta_k (x_{k,max} - x_{k,\min})}{\sum_l \beta_l (x_{l,max} - x_{l,\min})} \times 100 \tag{5}$$

4. Data and Survey Design

This study used stated preference (SP) data from choice experiments to analyze consumer preferences for virtual market conditions of hydrogen refueling stations. The data were collected in different regions of South Korea to reflect demographic distribution. The survey was conducted twice, and respondent ages ranged from 20s to 60s. The pilot survey was conducted online from April 6 to April 9, 2020. Using the pilot survey, the questionnaire was refined to improve readability and respondent understanding. The main survey was conducted online from May 11 to May 19, 2020 by Gallup Korea, a specialized survey company. Table 1 shows the demographic distribution of respondents.

Table 1. Demographic properties of sample.

Category	Characteristic	Respondents (n)	Percentage (%)
Total		850	100.0
Gender	Male	447	52.6
	Female	403	47.4
Age	20–29	168	19.8
	30–39	180	21.2
	40–49	218	25.6
	50–59	180	21.2
	60–69	104	12.2
Education Level	High school or less	124	14.6
	University/college or above	726	85.4

The survey questions were in two parts. Part 1 asked questions about respondent demographic characteristics and perceptions of various problems, current status of car ownership, usual mode of operation, and recognition of hydrogen energy. The results of part 1 show that 60% of respondents know where the electric charger is located. However, only 15% of respondents know the location of the hydrogen refueling station. This can be interpreted as a result of the lesser popularization of FCEVs than BEVs. In April 2020, 103,700 BEVs were adopted in Korea, while only 7033 FCEVs were adopted. Additionally, only 12% of respondents know that there is an additional waiting time during FCEV refueling. Attributes considered important when purchasing FCEVs were price (21.9%), safety (15.4%), automobile type (13.5%), and access to infrastructure (1.9%). Overall, 12.6% of respondents answered that accessibility of infrastructure is important among the top five attributes. Accessibility of infrastructure is a top five attribute for 36.4% of BEV owners. This indicates that infrastructure can be a significant inconvenience when AFVs are used, but for respondents who do not use them, there is a lack of awareness of the importance of infrastructure.

In part 2, a choice experiment was performed to grasp the structure of consumer preferences of a hydrogen refueling station. A choice experiment is a method used to present a combination of products with hypothetical characteristics to consumers and allows respondents to reveal preferences that can be measured [47]. Existing research that studied AFVs included fuel cost, driving range, refueling time, accessibility, and emission. Considering this, the survey covers six attributes to analyze consumer preferences of hydrogen refueling stations: (1) hydrogen fuel production method; (2) distance from home to hydrogen fueling station; (3) fuel cost; (4) number of dispensers of low pressure; (5) number of dispensers of high pressure; (6) probability of being unable to refuel due to lack of hydrogen.

Firstly, the respondents' environmentalism is considered through their preference of hydrogen production method. As discussed in Section 2, people who are more aware of the environment tend to be more sensitive to CO_2 emissions when selecting automobiles or prefer AFVs [30]. FCEV use does not generate emissions. However, fossil fuels can be used in producing hydrogen fuel. In this study, green hydrogen is presented as an eco-friendly fuel, and gray hydrogen is presented as being produced by fossil fuels.

Secondly, accessibility is reflected by distance from home to hydrogen refueling station. Many studies set the level of accessibility as the percentage of gas stations. However, this can increase the cognitive burden on respondents, leading to inappropriate results. In May 2020, there are 21,723 electric car charging stations and 26 hydrogen refueling stations in Korea. About 14.5% of electric car charging stations in Korea are installed in residential areas like supermarkets and convenience stores. In addition, the average daily driving range of Koreans (national, based on passenger cars) is 39.2 km/car [48]. This showed a driving range of up to 20 km for one-way travel. Thus, the level of accessibility is assumed to be from 1 km to 20 km.

Thirdly, supply stability can be explained by the standby time after arriving at the refueling station and refueling failure probability. Hydrogen volume causes problems in transportation and storage [19], which allows only 50 FCEVs per day to refuel at hydrogen stations with the current technology. Accordingly, when visiting a station, the inconvenience is reflected in the probability of failure if the remaining hydrogen in the refueling station is exhausted. Additionally, refueling time and the miles on a full charge of the FCEV differ depending on the kind of the dispenser. A low-pressure dispenser (350 bar) takes three minutes to increase the hydrogen pressure for refueling and five minutes to refuel and can travel up to 300 km. A high-pressure dispenser (700 bar) takes nine minutes to increase the hydrogen pressure and five minutes to refuel and can travel up to 600 km. Therefore, refueling time, miles on a full charge, and estimated standby time differ depending on the type of dispenser. Thus, two types of dispenser are designated for the virtual hydrogen refueling station. In May 2020, the average number of dispensers for electric vehicle charging stations in Korea is 1.85, with the following specific results: one unit (52.3%), two units (23.2%), three units (6.6%), four units (3.9%), and five or more units (14.1%). Therefore, one to four dispensers are shown for each type.

The economical attribute was considered through fuel costs. The unit of fuel efficiency of FCEVs is Korean won(KRW)/kg, but as a result of the pilot survey, the general consumer lacks awareness of FCEVs, so it is difficult for respondents to answer when presented with the fuel efficiency unit of FCEVs. Therefore, the fuel efficiency is presented in units of KRW/km. In consideration of the previous study, the prices are suggested from KRW 50/km to equidistant intervals [22,24,31]. Fuel efficiency is based on Nexo, South Korea's first commercial FCEV, to help respondents understand. Table 2 shows the attributes and levels determined by this study.

Table 2. Attributes and levels.

Attribute	Levels
Hydrogen fuel production method	gray, green
Distance from home to hydrogen fueling station	1 km, 4 km, 10 km, 20 km
Fuel cost	50 KRW, 100 KRW, 150 KRW, 200 KRW
No. of dispensers of low pressure	1, 2, 3, 4
No. of dispensers of high pressure	1, 2, 3, 4
Probability of failure to refuel	one of 50 visits, one of 20 visits, one of 10 visits, one of 5 visits

The number of cases of $2 \times 4 \times 4 \times 4 \times 4 \times 4 = 2048$ is required to represent all the properties and levels set in this study. As the number of all cases cannot be presented to respondents, the total number of alternatives is reduced to 32 by constructing fractional factorial design. Thereafter, four alternatives were grouped into one set for respondents to state preferences. Among the total of eight alternative sets, four sets are randomly presented to the respondents.

5. Results and Discussion

The mixed logit was used for the analysis, and normal distribution was assumed for all variables. MSL was used as the estimation method, and random draws for simulation were performed 100 times through the Halton method. When the number of draws is 100 or more, there is no significant difference in coefficient [49]. The empirical research model is represented in Equation (6).

$$U_{nj} = \beta_1 X_{Green} + \beta_2 X_{\text{Distance}} + \beta_3 X_{No.of\ refueling\ guns} + \beta_4 X_{High\ pressure\ charger\ ratio} + \beta_5 X_{Failure} + \beta_6 D_{Fuel} + \varepsilon_{nj} \quad (6)$$

In Equation (6), X_{Green} is a dummy variable for the hydrogen supplied, which is expressed as 1 for green hydrogen and 0 for gray hydrogen. The variables X_{Distance}, $X_{No.\ of\ refueling\ guns}$, $X_{Failure}$, and D_{Fuel} correspond to distance, total number of dispensers, and probability of refuel failure, respectively. $X_{High\ pressure\ charger\ ratio}$ represents the ratio of high-pressure dispensers to total number of dispensers.

The analysis results are shown in Table 3. When the production method was green hydrogen, the distance was closer, the total number of dispensers was greater, the probability of refuel failure was lower, and the fuel cost was lower, participants showed increased preference for hydrogen refueling stations. Distribution was found to be significant when normal distribution was assumed for the production method, distance, probability of failure of refueling, and cost of refueling. Therefore, there was heterogeneity in consumer preference. However, for the total number of dispensers and the ratio of high-pressure dispensers, heterogeneity was not revealed in preference of consumers, so the analysis was conducted with a fixed coefficient rather than an assumption of distribution for these attributes. As for RI, fuel cost was the most important, followed by probability of failure, eco-friendliness of production method, distance, and total number of dispensers.

Table 3. Estimation results of mixed logit model for hydrogen refueling station (base model).

Attribute	Assumed Distribution	Mean of β		Variance of β		MWTP (KRW)	RI
Green	Normal	1.0473	***	−1.1779	***	83.2464	19.42%
Distance (km)	Normal	−0.0521	***	0.0871	***	4.1441	18.36%
No. of dispensers	Fixed	0.0529	***	-		4.2015	5.88%
Ratio of high-pressure dispenser (%)	Fixed	0.0901		-		-	-
Failure (%)	Normal	−0.0640	***	0.0066	***	5.0871	21.36%
Fuel cost (KRW/km)	Normal	−0.0126	***	0.0008	***	-	34.98%

Note: *** Significant at the 1% level.

While total number of dispensers impacts preference, there was no difference in preference for each type of dispenser. The low-pressure dispensers and the high-pressure dispensers were considered separately, but preferences for each were not separated. For the hydrogen production method, when produced with green hydrogen, consumer preference was greater than when produced with gray hydrogen. This indicates that consumers may be willing to pay an additional fee to operate the FCEV in an eco-friendly way. Consumers are willing to pay an average of KRW 83.25/km if they are improved to an eco-friendly hydrogen production method rather than gray hydrogen. Currently, the average operating cost of FCEV is KRW 85.40/km (calculated based on Korea's average charging cost (KRW 8216.7/kg) and Hyundai Nexo's fuel economy (96.2 km/kg)), and when operating with green hydrogen, consumers are willing to pay KRW 168.66/km. Considering the current number of cars registered per vehicle age and the average annual five-cycle fuel cost, the average cost per kilometer of a general vehicle is KRW 121.93/km (calculated by considering the weighted average of the number of registered vehicles by age and average fuel efficiency by year with average fuel cost at the time of the survey (2020.4.6–2020.4.9)), which means that consumers are willing to pay up to KRW 46.73/km to reduce greenhouse gas emissions.

The results show that as the distance between home and hydrogen refueling station increases, consumer preference decreases. WTP is KRW 4.14/km as the distance to the refueling station gets closer by one kilometer. This indicates that people are willing to pay 4.9% more to bring the refueling station closer to one kilometer. Compared with previous studies, the better accessibility, the higher the market preference [22,24,31]. This shows that the results of this study are in line with related studies. The word hydrogen is reminiscent of danger and explosion [18]; therefore, people can hesitate to desire a hydrogen station near home. However, according to the results of model 3, there were no inflection points within the proposed distance, demonstrating that consumers prefer hydrogen refueling stations closer to their homes.

The probability of failure is the second most important attribute after the fuel cost. This means that people prefer refueling stations that do not have a probability of failure to refuel, and they are willing to go 1.23 km further to reduce the probability of failure by 1%. If expressed as an expense, consumers are willing to pay an additional KRW 5.09/km to reduce the probability of failure to refuel by 1%. This means that consumers are willing to pay around 6% more of the current refueling cost.

The probability of failure to refuel is related to the transportation and storage of the hydrogen refueling station, and according to the South Korean government's "hydrogen technology development roadmap", the hydrogen refueling station can supply up to 250 kg of hydrogen per day. This is enough fuel for approximately 50 FCEVs. According to this survey, the average number of refueling times per month for vehicle owners is 3.55, and assuming that the frequency of refueling of FCEVs is the same, the number of FCEVs that can be handled by only one hydrogen refueling station is 423. However, this assumes that all FCEVs are uniformly allocated to the hydrogen refueling station, so the actual number of FCEVs that a single station can refuel is further reduced. South Korea expects 650,000 cars by 2022 and 2.75 million cars by 2040 for domestic use, with 310 and 1200 hydrogen refueling stations planned, respectively. Conservatively, in 2022, 153 hydrogen refueling stations will meet the demand for 650,000 FCEVs. Therefore, the government plan does not affect the probability of refueling failure. However, conservative calculations from this study show that, while at least 6501 hydrogen refueling stations are required, the planned number of hydrogen refueling station is 1200. Therefore, the number of hydrogen refueling stations cannot meet the demand of FCEVs, and the probability of failure to refuel increases, hindering the growth of FCEVs. To prevent this, an increase in the number or capacity of hydrogen refueling stations and an increase in fuel consumption must be supported.

The RI of the number of dispensers is the lowest compared to other attributes, indicating small difference in preference between the two dispensers. Alternatively, respondents may not understand the difference between the dispensers, or the background knowledge of respondents may be insufficient due to the lack of sufficient hydrogen refueling stations. Additional analysis is conducted to consider perception, knowledge, and fuel type. The estimation results are shown in Table 4. The variable of *Statement* represents the perception difference between green and gray hydrogen and is measured on a five-point Likert scale. If respondents answered more than three, *Statement* is 1, otherwise 0. The variable of *Knowledge* represents an accurate knowledge of green and gray hydrogen and is measured based on several questions. If the respondent's answer is correct, *Knowledge* is 1, otherwise 0. The variables of *Driver (Fossil)* and *Driver (Environ)* represent fuel types. If respondents used gasoline or diesel vehicles, *Driver (Fossil)* is 1. If respondents used BEVs or FCEVs, *Driver (Environ)* is 1.

Table 4. Estimation results of mixed logit model for hydrogen refueling station (interaction included).

Attribute	Assumed Distribution	Model 2		Model 3		Model 4		Model 5	
		Mean of β	Variance of β	Mean of β	Variance of β	Mean of β	Variance of β	Mean of β	Variance of β
Green	Normal	1.1961 ***	1.0638 ***	1.0575 ***	1.1767 ***	1.0516 ***	1.1543 ***	1.0539 ***	1.1589 ***
Green×Statement	Normal	−0.9149 ***	0.1481						
Green×Knowledge	Normal	0.7702 ***	−0.7716						
Distance (km)	Normal			−0.0793 ***	0.0789 ***	−0.0328 ***		−0.0516 ***	0.0859 ***
Distance^2	Normal			0.0013 *	−0.0012				
Distance×Driver (Fossil)	Normal					−0.0240 **			
Distance×Driver (Environ)	Normal	−0.0511 ***				−0.0466 *	0.0637 ***		
No. of refueling dispenser	Fixed	0.0487 ***		0.0535 ***		0.0472 **	0.0648 ***	0.0499 ***	
High-pressure dispenser ratio (%)	Fixed	0.0759	0.0851 ***	0.1466		0.0905	0.0806 *	0.0787	
Failure (%)	Normal	−0.0645 ***	0.1066 ***	−0.0656 ***	0.1129 ***	−0.0639 ***	0.1090 ***	−0.0638 ***	0.1090 ***
Failure×Driver (Fossil)	Normal							−0.0025	−0.0337 *
Failure×Driver (Environ)	Normal							0.0128	−0.0085
Fuel cost (KRW/km)	Normal	−0.0126 ***	−0.0139 ***	−0.0128 ***	0.0139 ***	−0.0126 ***	−0.0138 ***	−0.0125 ***	0.0139 ***

Note: *** Significant at the 1% level; ** Significant at the 5% level; * Significant at the 10% level.

The WTP for reducing 1% of a vehicle's average CO2 emissions is indicated by 20 to 90 EUR depending on respondents' environmental awareness [38]. The WTP for green hydrogen depends on respondent knowledge of gray and green hydrogen. Interestingly, WTP is different between those who think that they know the difference between gray and green hydrogen and those who actually know. In this survey, 202 respondents state that they know the difference between green hydrogen and gray hydrogen (at least three points on the Likert scale). However, only 80 of the 202 respondents actually know the difference. According to Model 2, if respondents answered that they know the difference between green hydrogen and gray hydrogen in advance, they are willing to pay more, up to KRW 22.38/km. This is a significant decrease compared to KRW 95.19/km, the WTP of respondents who answered that they did not know the difference. However, for respondents that actually know the difference, their willingness-to-pay was KRW 83.68/km, which was lower than the willingness-to-pay of those who answered that they do not know but similar to the overall average. Therefore, respondents who answered that they know the difference between the two types of hydrogen but did not actually know the difference do not intend to pay more than KRW 121.93/km, which is the average oil ratio of traditional fossil fuel-based cars. However, if respondents know the difference, they are willing to pay more than current oil costs. This result suggests that, when switching from gray hydrogen to green hydrogen production, priority should be given to publicizing the difference between the two hydrogens to help improve the environment.

According to Model 4, the preference for approaching the hydrogen refueling station is more sensitive to drivers than non-drivers. Of 850 respondents, 622 were drivers, 561 were owners of fossil fuel vehicles, and 44 were owners of eco-friendly vehicles. Drivers of eco-friendly cars were more sensitive to distance. Actual drivers value hydrogen refueling stations within the range of travel. Drivers of fossil fuel vehicles were willing to travel up to 4.51 km more, and eco-friendly drivers were willing to travel up to 6.31 km more.

6. Conclusions

Although many studies presented the importance of the AFV and its infrastructure, specific measures for the FCEV infrastructure, hydrogen refueling stations, have not been provided. This study presents a quantitative analysis of consumer preferences for FCEV infrastructure. The preferences were analyzed by considering five issues of a hydrogen station: fuel costs related to economic performance, production methods related to environmental performance, average distance related to accessibility, waiting time, and refueling failure related to supply stability.

Depending on the type of energy used in production, hydrogen is green and does not emit greenhouse gases, or it is gray and does emit greenhouse gases. The results of this study show that respondents are willing to pay more for green hydrogen than gray hydrogen. The current hydrogen refueling cost in Korea is about two-thirds the price of the average fueling cost of gasoline cars due to government support, so FCEVs have the advantage of low maintenance costs. However, this study finds that, for environmental reasons, consumers will pay the FCEV maintenance cost even if it is higher than the current fossil fuel vehicle maintenance cost. Additionally, the WTP is KRW 4.14/km due to a 1-km reduction in accessibility. Consumers will pay 4.9% more than the current cost, and drivers are willing to pay more than non-drivers. Eco-friendlier drivers are more sensitive to accessibility, suggesting that accessibility is an important issue for the growth of FCEVs.

In this study, the waiting time was reflected by the number of dispensers, which are divided into high-pressure and low-pressure dispensers for the analysis. The difference in preference according to the dispenser pressure was not revealed, but the higher the total number of dispensers, the more preferred. A preference for avoiding waiting time for refueling was found. However, the minimum options for the number of dispensers were set to one high-pressure and one low-pressure dispenser, which is a limitation in the study's analysis. Consumers will travel 1.23 km further or pay 6% more for fuel to avoid even a 1% increase in the probability of failure of refueling. Current hydrogen refueling stations cannot refuel more than 50 FCEVs per day, and there is a lack of plans to open hydrogen refueling stations, according to the 2040 FCEV supply plan in Korea. To operate hydrogen refueling stations and distribute FCEVs smoothly, problems such as increasing the capacity of hydrogen refueling stations, increasing the number of hydrogen refueling stations and improving FCEV fuel efficiency are suggested.

This study provides three implications. Firstly, this paper analyzes the design of hydrogen refueling stations through quantitative aspects. We analyzed the consumer preference structure for the specific design of hydrogen refueling stations using choice experiment methods. In addition, the mixed logit model reflected the heterogeneity of the individual, and the estimation results were statistically significant results. Secondly, the analysis shows that four important results can be categorized into environment, accessibility, supply stability, and cost perspectives. Thirdly, for policy makers, this study provides a quantitative basis for FCEV deployment plans and implications for other AFV infrastructure issues. Accessibility and supply stability are issues that have trade-offs if not supported by production capacity. Therefore, if hydrogen refueling stations are built based on the quantified results of this study, optimal planning can be established by considering the production method, number of hydrogen refueling stations, location, and number of dispensers.

The limitations of this study are as follows. Changes in attributes and levels of hydrogen refueling stations interact with changes in FCEV deployment. Therefore, more accurate implications can be presented when waiting time, probability of failure of refuel, and accessibility calculations consider spatial dimension for hydrogen refueling stations. This study only considered the distance of hydrogen refueling station. In future studies, this will be considered organically, and more accurate diffusion prospects and diffusion inhibitors can be identified. In addition, based on up-to-date technologies such as Internet of Things sensors, the spatial dimensions and usage of information about energy systems can be collected in the future. Using real-time data, a deployment plan can be also provided.

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References

1. IEA. Tracking Transport 2019. Available online: https://www.iea.org/reports/tracking-transport-2019 (accessed on 24 July 2020).
2. Sørensen, B.; Spazzafumo, G. *Hydrogen and Fuel Cells: Emerging Technologies and Applications*; Academic Press: Cambridge, MA, USA, 2018.
3. Propfe, B.; Kreyenberg, D.; Wind, J.; Schmid, S. Market penetration analysis of electric vehicles in the German passenger car market towards 2030. *Int. J. Hydrogen Energy* **2013**, *38*, 5201–5208. [CrossRef]
4. IEA. Global EV Outlook 2019. Available online: https://www.iea.org/reports/global-ev-outlook-2019 (accessed on 24 July 2020).
5. IEA. Tracking Energy Integration 2019. Available online: https://www.iea.org/reports/tracking-energy-integration-2019 (accessed on 24 July 2020).
6. Hayes, J.G.; Goodarzi, G.A. *Electric Powertrain: Energy Systems, Power Electronics and Drives for Hybrid, Electric and Fuel Cell Vehicles*; John Wiley & Sons: Hoboken, NJ, USA, 2018.
7. Melaina, M.W.; Bush, B.W.; Muratori, M.; Zuboy, J.; Ellis, S. *National Hydrogen Scenarios: How Many Stations, Where, and When? No. NREL/TP-5400-71083*; National Renewable Energy Lab.(NREL): Golden, CO, USA, 2018.
8. Das, H.S.; Tan, C.W.; Yatim, A.H.M. Fuel Cell Hybrid Electric Vehicles: A Review on Power Conditioning Units and Topologies. *Renew. Sustain. Energy Rev.* **2017**, *76*, 268–291. [CrossRef]
9. Byun, H.; Shin, J.; Lee, C.Y. Using a Discrete Choice Experiment to Predict the Penetration Possibility of Environmentally Friendly Vehicles. *Energy* **2018**, *144*, 312–321. [CrossRef]
10. IEA. Tracking Progress 2020. Available online: https://www.iea.org/reports/hydrogen (accessed on 24 July 2020).
11. Gyeonggi Research Institution. *A Study on the Construction of Hydrogen Refueling Station in Gyeonggi-Do, Policy Research*; Gyeonggi Research Institution: Suwon, Korea, 2019.
12. Korea Ministry of Trade, Industry and Energy. Hydrogen Economy Roadmap. Available online: https://policy.nl.go.kr/search/searchDetail.do?rec_key=SH2_PLC20190231080 (accessed on 17 January 2019).
13. Adolf, J.; Balzer, C.H.; Louis, J.; Schabla, U.; Fischedick, M.; Arnold, K.; Pastowski, A.; Schüwer, D. Energy of the Future?: Sustainable Mobility through Fuel Cells and H2; Shell Hydrogen Study. 2017. Available online: https://epub.wupperinst.org/frontdoor/index/index/docId/6786 (accessed on 24 July 2020).
14. Melaina, M.W. Initiating Hydrogen Infrastructures: Preliminary Analysis of a Sufficient Number of Initial Hydrogen Stations in the US. *Int. J. Hydrog. Energy* **2003**, *28*, 743–755. [CrossRef]
15. Köhler, J.; Wietschel, M.; Whitmarsh, L.; Keles, D.; Schade, W. Infrastructure Investment for a Transition to Hydrogen Automobiles. *Technol. Forecast. Soc. Chang.* **2010**, *77*, 1237–1248. [CrossRef]
16. Koroneos, C.; Dompros, A.; Roumbas, G.; Moussiopoulos, N. Life Cycle Assessment of Hydrogen Fuel Production Processes. *Int. J. Hydrogen Energy* **2004**, *29*, 1443–1450. [CrossRef]
17. Oshiro, K.; Masui, T. Diffusion of Low Emission Vehicles and Their Impact on CO_2 Emission Reduction in Japan. *Energy Policy* **2015**, *81*, 215–225. [CrossRef]
18. Martin, E.; Shaheen, S.; Lipman, T.; Lidicker, J. Behavioral Response to Hydrogen Fuel Cell Vehicles and Refueling: A Comparative Analysis of Bulletin of Science. *Technol. Soc.* **2006**, *26*, 339–345.
19. Ball, M.; Wietschel, M. (Eds.) *The Hydrogen Economy: Opportunities and Challenges*; Cambridge University Press: Cambridge, UK, 2009.
20. Najjar, Y.S. Hydrogen Safety: The Road toward Green Technology. *Int. J. Hydrogen Energy* **2013**, *38*, 10716–10728. [CrossRef]
21. Gnann, T. *Market Diffusion of Plug-In Electric Vehicles and Their Charging Infrastructure*; Fraunhofer: Stuttgart, Germany, 2015.
22. Hackbarth, A.; Madlener, R. Willingness-To-Pay for Alternative Fuel Vehicle Characteristics: A Stated Choice Study for Germany. *Transp. Res. Part A Policy Pr.* **2016**, *85*, 89–111. [CrossRef]
23. Choi, H.; Park, S.; Lee, J.D. Government-Driven Knowledge Networks as Precursors to Emerging Sectors: A Case of the Hydrogen Energy Sector in Korea. *Ind. Corp. Chang.* **2011**, *20*, 751–787. [CrossRef]

24. Shin, J.; Hwang, W.S.; Choi, H. Can Hydrogen Fuel Vehicles be a Sustainable Alternative on Vehicle Market? Comparison of Electric and Hydrogen Fuel Cell Vehicles. *Technol. Forecast. Soc. Chang.* **2019**, *143*, 239–248. [CrossRef]
25. Kim, J.H.; Kim, H.J.; Yoo, S.H. Willingness to Pay for Fuel-Cell Electric Vehicles in South Korea. *Energy* **2019**, *174*, 497–502. [CrossRef]
26. Gnann, T.; Plötz, P. A Review of Combined Models for Market Diffusion of Alternative Fuel Vehicles and their Refueling Infrastructure. *Renew. Sustain. Energy Rev.* **2015**, *47*, 783–793. [CrossRef]
27. BCG. *The Boston Consulting Group: The Comeback of the Electric Car? How Real, How Soon, and What Must Happen Next, Technical Report*; BCG: Boston, MA, USA, 2009.
28. Kalhammer, F.R.; Kopf, B.M.; Swan, D.H.; Roan, V.P.; Walsh, M.P. Status and Prospects for Zero Emissions Vehicle Technology. *Rep. ARB Indep. Expert Panel* **2007**, *1*, 12–36.
29. Hardman, S.; Tal, G. Who are the Early Adopters of Fuel Cell Vehicles? *Int. J. Hydrogen Energy* **2018**, *43*, 17857–17866. [CrossRef]
30. Tanç, B.; Arat, H.T.; Baltacıoğlu, E.; Aydın, K. Overview of the Next Quarter Century Vision of Hydrogen Fuel Cell Electric Vehicles. *Int. J. Hydrogen Energy* **2019**, *44*, 10120–10128. [CrossRef]
31. Li, W.; Long, R.; Chen, H.; Chen, F.; Zheng, X.; He, Z.; Zhang, L. Willingness to Pay for Hydrogen Fuel Cell Electric Vehicles in China: A Choice Experiment Analysis. *Int. J. Hydrogen Energy* **2020**. [CrossRef]
32. Ziegler, A. Individual Characteristics and Stated Preferences for Alternative Energy Sources and Propulsion Technologies in Vehicles: A Discrete Choice Analysis for Germany. *Transp. Res. Part A Policy Pr.* **2012**, *46*, 1372–1385. [CrossRef]
33. Yang, H.J.; Cho, Y.; Yoo, S.H. Public Willingness to Pay for Hydrogen Stations Expansion Policy in Korea: Results of a Contingent Valuation Survey. *Int. J. Hydrogen Energy* **2017**, *42*, 10739–10746. [CrossRef]
34. IEA. *Technology Roadmap: Hydrogen and Fuel Cells*; International Energy Agency: Paris, France, 2015.
35. Longo, A.; Markandya, A.; Petrucci, M. The Internalization of Externalities in the Production of Electricity: Willingness to Pay for the Attributes of a Policy for Renewable Energy. *Ecol. Econ.* **2008**, *67*, 140–152. [CrossRef]
36. Carlsson, F.; Johansson-Stenman, O. Willingness to Pay for Improved Air Quality in Sweden. *Appl. Econ.* **2000**, *32*, 661–669. [CrossRef]
37. Hackbarth, A.; Madlener, R. Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis. *Transp. Res. Part D Transp. Environ.* **2013**, *25*, 5–17. [CrossRef]
38. Liang, Y.; Pan, X.; Zhang, C.; Xie, B.; Liu, S. The Simulation and Analysis of Leakage and Explosion at a Renewable Hydrogen Refuelling Station. *Int. J. Hydrogen Energy* **2019**, *44*, 22608–22619. [CrossRef]
39. Lee, K.; Lee, J.; Yong, K. Strategies for Practical Use of Hydrogen Cars in Korea. *Korean Hydrog. New Energy Soc.* **2010**, *21*, 346–353.
40. Train, K.E. *Discrete Choice Methods with Simulation*; Cambridge University Press: Cambridge, UK, 2009.
41. Train, K.; Sonnier, G. Mixed Logit with Bounded Distributions of Correlated Partworths. In *Applications of Simulation Methods in Environmental and Resource Economics*; Springer: Dordrecht, The Netherlands, 2005; pp. 117–134.
42. Lee, J.; Choi, J.Y.; Cho, Y. A Forecast Simulation Analysis Of The Next-Generation Dvd Market Based On Consumer Preference Data. *Int. J. Consum. Stud.* **2011**, *35*, 448–457. [CrossRef]
43. Shin, J.; Park, Y.; Lee, D. Strategic Management of Over-the-Top Services: Focusing on Korean Consumer Adoption Behavior. *Technol. Forecast. Soc. Chang.* **2016**, *112*, 329–337. [CrossRef]
44. Koo, Y.; Lee, M.; Cho, Y. A Point Card System for Public Transport Utilization in Korea. *Transp. Res. Part D Transp. Environ.* **2013**, *22*, 70–74. [CrossRef]
45. Shin, J.; Woo, J.; Huh, S.Y.; Lee, J.; Jeong, G. Analyzing Public Preferences and Increasing Acceptability for the Renewable Portfolio Standard in Korea. *Energy Econ.* **2014**, *42*, 17–26. [CrossRef]
46. Hyslop, D.R. State Dependence, Serial Correlation and Heterogeneity in Intertemporal Labor Force Participation of Married Women. *Econometrica* **1999**, *67*, 1255–1294. [CrossRef]
47. Green, P.E.; Srinivasan, V. Conjoint Analysis in Consumer Research: Issues and Outlook. *J. Consum. Res.* **1978**, *5*, 103. [CrossRef]

48. Statistics Korea. *Average Mileage of Automobile in 2018*; Statistics Korea: Daejeon, Korea, 2018.
49. Stewart, M. Maximum simulated likelihood estimation of random-effects dynamic probit models with autocorrelated errors. *Stata J.* **2006**, *6*, 256–272. [CrossRef]