Understanding attitudes of hydrogen fuel-cell vehicle adopters in Japan

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Abstract:

As of January 2021, Japan had the world's largest hydrogen station network with merely 4,600 hydrogen fuel-cell vehicles (HFCVs) on roads, as compared to the 9,000 HFCVs in the US, with only one-third of the hydrogen refueling stations in Japan. To understand behavioral differences among Japanese adopters, we administered a survey, in cooperation with public and private sector stakeholders, involving 89 private HFCV adopters in the Aichi Prefectural region, which hosts the largest number of HFCVs and refueling stations in Japan. Results suggest that HFCV adopters have a higher socioeconomic status than non-adopters, are mostly male in their 50s and above, and have a higher interest in new vehicle fuel technology. HFCV adopters who leased and bought vehicles were similar in terms of socioeconomic status, with differences in attitudes toward governmental incentives. The lack of refueling stations and station business hours restrict HFCV adopters from continuing with this fuel technology.

Keywords: Hydrogen fuel-cell vehicles; Hydrogen refueling stations; New vehicle fuel technology; Attitudes

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1. Introduction

In the first address of the parliament in October 2020, Japan's new Prime Minister Yoshihide Suga announced a major shift in position on climate change. In the policy address, he unveiled Japan's commitment to cut emissions to zero and become a carbon-neutral society by 2050. Some policymakers had raised fears of a slump in economic growth due to assertive measures against climate change. However, PM Suga made it clear that measures to combat climate change will no longer be a restraint in the path to economic growth. This policy shift puts Japan in line with the European Union, which also aims to achieve carbon neutrality by 2050. Following the pledge, lawmakers aim to phase out gasoline-powered automobiles from Japanese roads by the first half of the 2030s, making Japan the second G-7 economy after the United Kingdom to set an explicit target in halting sales of new fossil fuel-based cars. To shepherd PM Suga's pledge, the government intends to incentivize 14 industries, including the hydrogen sector.

The first-generation Toyota Mirai, which is also the world's first mass-produced hydrogen vehicle, went on sale in late 2014. The revised roadmap of 2016 highlighted the government's intention to have 40,000 HFCVs, 160 hydrogen refueling stations, and 1.4 million residential fuel cells by 2020. Despite the efforts to meet the 2020 HFCV sales target, there were only 4,000 HFCVs on Japanese roads by March 2020, as against 8,931 in the US. As of October 2020, Japan has 135 hydrogen station networks spread across the country and ranks the highest in the number of hydrogen refueling stations worldwide.

Earlier studies highlighted the high purchase price, sparse hydrogen station network, and safety as an impediment to the successful adoption of HFCVs [1–9]. Leibowicz [4] analyzed the transition to new vehicle technologies based on the historical diffusion dynamics of transport systems in the United States. The study results highlighted the full-fledged development of the charging/refueling infrastructure as a precondition for the successful diffusion of vehicles. To date, HFCV sales in Japan could only meet one-tenth of the original target set in 2016 to have 40,000 HFCVs by 2020. Some studies have linked the high upfront costs of these vehicles compared to traditional vehicles as a psychological barrier in adopting HFCVs [3,10].

Japan unveiled the world's largest green hydrogen facility, "Fukushima Hydrogen Energy Research Field" (FH2R), in 2020, which can refuel 520 HFCVs per day. Recently, the sector has experienced a race in the production of green hydrogen and rollout of hydrogen fuel vehicles worldwide. Canada inaugurated the world's largest green-hydrogen plant, having double the capacity of Japan's FH2R. Later in 2020, Toyota Motor Corporation launched the second-generation HFCV, a revamp of the first-generation Toyota Mirai. With an increase in the hydrogen storage capacity of the vehicle, the driving range increased by 30% compared to that of the Mirai. These environmental-friendly vehicles can be refueled in less than 5 minutes and offer a long cruising range of 850 km before the next refuel.

Japan is devoting efforts toward the realization of a hydrogen society and is considered a leader in developing hydrogen and its applications. However, the significantly low HFCV sales in the Japanese market raises potential concerns from a consumer perspective. A rich body of literature is available with studies on consumer behavior and perceptions of hydrogen and its applications in the USA and Europe [5,11–16]. However, the Japanese literature lacks recent empirical studies on hydrogen and its applications. This empirical research article attempts to investigate the behavior and attitudes of hydrogen vehicle owners. Earlier studies explain the process by which new technology successfully penetrates into the market, while others do not. In the history of technology adoption process, Rogers adoption model "Diffusion of Innovations" [17] outlines how, over time, any technology gains impetus and diffuses in a social system. The "Diffusion of Innovations" theory highlights the group of individuals who make reviews of the new technology or a product that they strongly like or dislike. These adopters are cognizant of the need to change and, therefore adopt new technology. The personality attributes of the early adopters include – younger in age, higher education levels, higher socio-economic status, and are socially forward than late adopters. Early adopters play an important role in the mass market success of any new technology as they help in decreasing uncertainty about the new technology due to their central role in social communication system. Therefore, it is crucial to study the profile of HFCV early adopters in Japan.

Using empirical data from computer-assisted web interviewing (CAWI) and a mail questionnaire survey, we investigated hydrogen car owners' experience outlining HFCV performance, infrastructure, and safety. This study aims to examine the profile of current adopters of HFCVs and their attitudes toward HFCV and its applications. Policymakers can use this research work to make more knowledgeable policy decisions and companies involved in developing fuel-cell cars and hydrogen station networks can address relevant consumer challenges in adopting HFCVs.

The remainder of this paper is organized as follows. Section 2 presents an in-depth study of the current literature relevant to this study. In Section 3, the methodology used in this study was delineated, including how respondents were recruited for this empirical study. The results are presented in Section 4, and outlines the socioeconomic characteristics of the HFCV adopters, followed by an in-depth analysis of attitudinal responses on HFCVs and their applications. Finally, in section 5, the conclusions and policy implications of our study and limitations and directions for future research are presented.

2. Literature review

Research on HFCVs and their commercialization dates back to the 1990s when Toyota Motor Corporation exhibited its in-house-developed hydrogen vehicle [18]. Testing of HFCVs on public roads in Japan and the USA started in 2002. In the same year, as part of limited marketing, the company delivered four vehicles in the United States and two in Japan. In 2001, the Japanese government's "Action Plan for Disseminating Low Emission Vehicles" targeted 50,000 HFCVs by 2010 [19]. Ishitani and Baba [20] associated the missing target of 50,000 HFCVs with technical issues, the high price tag of fuel cells, and market immaturity. In 2011, Japanese automakers pledged to commercially introduce HFCV by 2015 [21]. The world's first commercially available hydrogen vehicle was launched in 2014 to successfully diffuse this fuel technology in an already competitive auto-market. Despite the entice of zero tailpipe emissions, HFCVs remain a niche portion of the auto-market.

The high price tag of the hydrogen vehicle and sporadic network of hydrogen stations creates a chicken-and-egg situation where automakers and associated companies advocating a hydrogen economy are reluctant to invest in new stations considering the low sales of these zero-emission vehicles, while consumers' likelihood to adopt HFCVs remains uncertain due to the lack of hydrogen refueling infrastructure and purchase price [22–34]. Earlier studies conducted in USA, Demark, South Korea, and China emphasis on the fact that addition of hydrogen as an alternative energy source along with other powertrains in the transportation network will assist in reducing the rising greenhouse gas emissions from the transport sector [35–41].

There is a wealth of research articles on alternative fuel vehicle (AFV) adoption focusing on attitudes, preferences, and behaviors of potential consumers using stated-preference discrete choice experiments. This technique requires presumed or potential AFV buyers to choose vehicle fuel technology of interest based on vehicle characteristics, that is, purchase price, mileage, maintenance cost, fuel type, performance, and safety, and measures the likelihood of the respondent's choice of vehicle type [42–49]. Some studies have highlighted the importance of vehicle attributes, including purchase price, driving range, and performance [42,50–54]. Personal characteristics and attributes such as travel pattern, income, age, environmental awareness, and knowledge of green fuel vehicles were also found to influence consumers' purchasing decisions [55–61]. Studies involving data from presumed or potential vehicle adopters can have limitations in understanding consumers' experiences with specific fuel technology. Thus, research involving actual adopters who have already driven or experienced the fuel technology can better guide the researchers in evaluating consumers' discernment. This study systematically reviews previous studies involving consumers with experience in driving HFCVs.

The recent empirical study by Kelley et al. [62] highlighted the diverse behavior of respondents buying HFCV, such as lifestyle, societal image, governmental incentives, and hydrogen refueling statios' location. The results implied that respondents give weightage to "near home" hydrogen stations but use stations far from homes for long trips. Hardman [63] studied the socioeconomic profiles of 906 HFCV and 12,910 battery electric vehicle (BEV) adopters in California. Compared to BEV households, HFCV households were more educated, had relatively higher income, more vehicle miles traveled, and owned more than two vehicles.

Jaramillo et al. [64] conducted semi-structured interviews with 12 early adopters of HFCVs in California. Sufficient HFCV refueling networks and lifetime cost of vehicle ownership were determined as critical factors influencing HFCV purchasing decisions. In an exploratory study conducted in California, Hardman and Tal [16] found differences in attitudes toward environmental sustainability, previous experience in using green fuel vehicles, and residential building type. Lipman et al. [65] investigated participant drivers' acceptance and perception of HFCV performance over a two-year vehicle trial period. More than 90% of the respondents reported that the refueling process was safer than gasoline refueling. Approximately 85% of the research subjects found hydrogen refueling to be simple.

An empirical study conducted by Schneider [66] investigated user perception of the hydrogen refueling infrastructure in Germany. The results implied that more than 90% of the respondents explicitly appreciated the short refueling time. The majority of the respondents (>90%) reported no safety concerns during the hydrogen refueling process. A research study by Hardman et al. [67] evaluated consumer behavior toward HFCVs in England. The results revealed that respondents perceived HFCV to be similar to traditional internal combustion engine vehicles. Respondents reported about high price tag of HFCV and scant hydrogen refuel infrastructure.

The HYCHAIN MINI-TRANS project provides citizens with an opportunity to test drive hydrogen-powered light-duty vehicles. Approximately 60% of the participants reported hydrogen vehicles "as safe as traditional vehicles" [68]. Martin et al. [69] investigated the discernment of 182 HFCV respondents in a vehicle trial. A sizable proportion of the sample (>80%) had a positive impression of hydrogen as a fuel. The results inferred that around 60% of the respondents would accept a 5–10 minutes detour for refueling. Generally, the authors underlined the significance of short-term exposure to HFCV experience, leading to a better impression of potential early adopters in terms of HFCV performance and safety. Shaheen et al. [70] reported a positive correlation between higher levels of hydrogen application and acceptance. The refueling process was felt safe, and with the increasing HFCV driving experience, respondents felt increasingly safer with the HFCV.

Table 1. Summary of research methods used in hydrogen fuel-cell vehicle literature

Author	Study area	Sample size (n)	Survey year	Sample characteristics	Key findings
Kelley et al. [62]	California	129	2019	HFCV owners	Hydrogen refuelling stations satisfy geographic criteria for drivers in a diversity of ways. Some prefer stations near home, to be sure, but others adopted the HFCVs while prioritizing convenience to other criteria
Hardman [63]	California	906	2018	HFCV owners	Households with little access to BEV charging point might have decided to adopt HFCV
Jaramillo et al. [64]	California	12	2018	HFCV owners	Respondents preferred HFCVs driving range, time, and cost over BEV
Hardman and Tal [16]	California	470	2017	HFCV owners	HFCV and BEV households differ in attitudes towards environment and previous experience using green fuel vehicles
Lipman et al. [65]	California	54	2016	Volunteered drivers	HFCV drivers found refuelling process safer than gasoline refuelling
Schneider [66]	Germany	114	2015	HFCV owners	Respondents appreciated HFCV's short refuelling time
Hardman et al. [67]	United Kingdom	30	2015	Exhibition participants	Respondents perceived HFCVs as similar to gasoline vehicles
Pietzner et al. [68]	Germany	32	2009	Public transport drivers	Respondents considered HFCV as safe as gasoline vehicles
Martine t al. [69]	California	182	2007	Volunteered drivers	Short-term refuelling time positively impact consumer's attitudes
Shaheen et al. [70]	California	65	2006	Volunteered drivers	Positive correlation between higher levels of hydrogen application and acceptance

From Table 1, we can establish that most of the earlier empirical studies come from outside Japan, especially California, US, for the following reasons. California is the only state in the US with multiple ongoing projects on hydrogen, considering its stringent emission regulations since the last decade. Recently, the California Air Resource Board embraced "Low-Emission Vehicle III," which pushes automakers to cut tailpipe emissions from new passenger vehicles. Since 2010, the state has been giving incentives worth up to 7,000 USD on green fuel vehicles. With more than three times fewer hydrogen stations in Japan, as of 2020, there are almost double the number of HFCVs running on the Golden State's roads. Therefore, it is crucial to investigate the reasons for the low number of HCVs on Japanese roads. Hence, an empirical study to probe consumers' attitudes toward HFCVs in Japan is relevant. Policy recommendations in most of the earlier studies on HFCVs have been established without empirical evidence from owners of HFCV [9,71-73].

In the Japanese literature on HFCVs, studies can be divided into two groups. The first is primarily centered on a methodological framework including proxy or hypothetical scenarios through a stated-preference discrete choice experiment to examine consumers' behavior on HFCVs and other vehicle powertrains, including BEVs, conventional vehicles (CVs), hybrid vehicles (HVs), and plug-in hybrid electric vehicles (PHEVs) [42,74-76]. Other studies have inferred results from case study data or gather corroboration from the general public visiting any exhibition on HFCV and its applications and ask them questions about perceptions of hydrogen safety, acceptance of H_2 refueling infrastructure, and use of H_2 as an energy source [77–81]. The most recent empirical study in the Japanese literature was conducted by Khan et al. [82], who examined the socioeconomic characteristics of potential early adopters of HFCVs. The study found a significant difference in income, knowledge of H_2, and its applications among hydrogen vehicle potential adopters and respondents with no interest in this powertrain. In one of the study conducted in 2019 in the Japanese market, only one respondent was owning HFCV and intended to replace it with other fuel technologies [42].

Given the nascent nature of the HFCV market and uncertainties in the policy recommendations on HFCV diffusion derived from the hypothetical scenarios in earlier studies, the current developments underline the need to consider the attitudes and behaviors of actual adopters. This research work is the most recent study on HFCVs in Japan and fills the literature gap by evoking actual hydrogen vehicle owners' experiences with zero-emission vehicle powertrain.

3. Data and methodology

The survey was undertaken in the Aichi Prefecture, located roughly in the center of Japan, from November 15, 2020, to January 31, 2021. Aichi Prefecture (Fig. 1) was selected for participant recruitment because of its distinct features, such as home to Toyota Motor Corporation's Motomachi plant having hydrogen-powered vehicle production lines, and Toyota's Ecoful Town powered by hydrogen fuel cells, and a prefecture with the largest number of registered HFCVs, and hydrogen refueling stations.

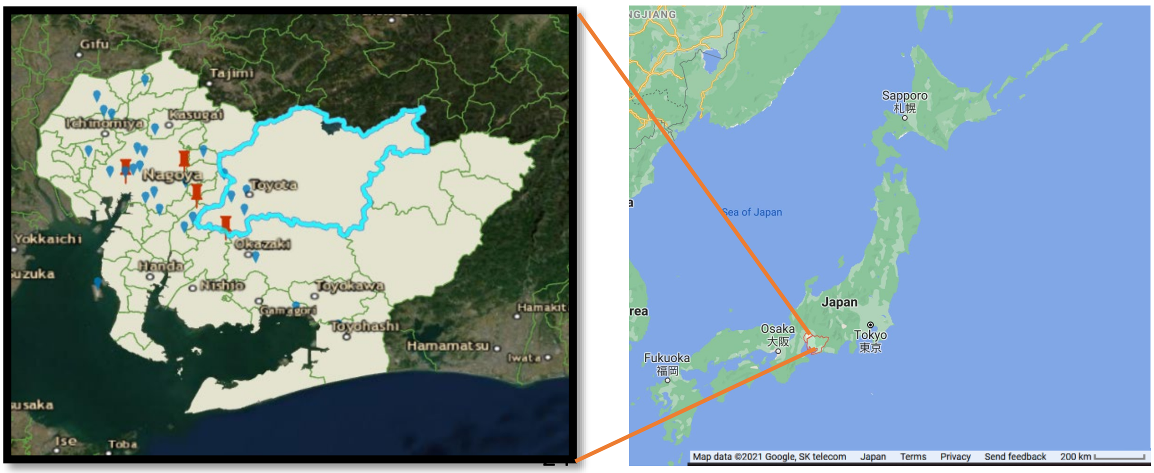

Fig 1. Hydrogen refueling stations in Aichi Prefectural area

In Figure 1, light blue bounded region shows Toyota City which comes under administrative boundary of the larger Aichi Prefectural area. The small red and blue icons on the map show the hydrogen stations that are currently operational in Aichi Prefectural area. Red icons represent stations where survey was conducted under this research project.

Respondents were recruited via two modes.

I. HFCV adopters who visited the designated hydrogen refueling stations operated by Toho Gas and ENEOS, formerly known as JXTG Nippon Oil & Energy Corporation, during the station business hours from November 15 to December 15, 2020. At four different hydrogen refueling stations, 73 questionnaires were distributed, of which 51 complete sheets were returned, entailing a response rate of 70%.

II. Residents who applied for the local government (Toyota City Government) incentives to purchase HFCVs. Among these respective Toyota city residents, 47 questionnaires were distributed, of which 38 complete sheets were returned, entailing a response rate of 81%.

In total, between Nov 15, 2020, to Jan 31, 2021, 120 questionnaire sheets were distributed. Of which 89 complete surveys were returned, entailing a response rate of 74.2%. Respondents were given two options to respond to the questionnaire: either to submit the responses online through the QR code to access the computer-assisted web interviewing (CAWI) questionnaire transcript or mail back the filled questionnaire sheet. At two of the hydrogen stations, questionnaires were distributed by the members of the research team while at other two stations, station staff distributed the sheets. All the information related to purpose of the survey and instructions to fill out were mentioned in detail. To assist the respondents in filling out the questionnaire sheets, research team members were positioned at the stations to assist the respondents. A non-probabilistic, purposive sampling was carried out among private HFCV owners. For increasing the response rate, respondents were given an option to apply monetary rewards on completing the questionnaire. Monetary incentives have previously been observed to increase the likelihood of returning a completed or partially completed questionnaire [83–85].

The questionnaire was structured in three parts:

I. Knowledge and information on HFCVs: HFCV ownership year and type, information on HFCVs, reasons for owning HFCV, source of information on HFCV.

II. Attitudes and opinions toward HFCVs: the satisfaction level on HFCV characteristics, relative importance of factors determining purchase of HFCVs, effect of policy incentives on the diffusion of HFCVs, average mileage per week, travel pattern, time to reach the nearest refueling stations, likelihood of the replacement of current HFCV, and reasons for the replacement of current HFCV.

III. Socioeconomic characteristics of the respondents: sex, age group, income, education level, residence type and ownership status, number of vehicles, and previous AFV experience.

The survey incorporated 5-point “Likert-item” type questions in the second part of the questionnaire, along with additional checkbox questions that allow respondents to choose multiple options, radio buttons, and few open-ended questions. A five-point Likert scale was used to evaluate the satisfaction level of several HFCV characteristics (very dissatisfied, dissatisfied, neutral, satisfied, and very satisfied). Descriptive statistics were obtained using frequency breakdown. The questionnaire was patterned to elicit respondents’ attitudes and perceptions of HFCVs. To further understand the profile of the HFCV adopters and non-adopters, awareness, knowledge, and perception of hydrogen vehicles and related technologies, we compared the results of the current survey with the recently conducted surveys in Aichi Prefecture on potential car buyers/non-HFCV adopters and company HFCV adopters by Nagoya University and Aichi Prefectural Government, respectively. Between October and November 2018, Nagoya University conducted computer-assisted web interviewing to gather data, of which description is shown in the appendix (Table A.1), from 500 potential car buyers in an attempt to understand the preferences and attitudes of the potential buyers towards HFCVs. The comparison of the private early adopter survey and the potential car buyer survey is crucial in understanding the difference between these two groups. The survey data in this study was examined using the chi-square test and t-test. These tests are used to examine similarities and differences between adopters and non-adopters and those who leased or bought HFCVs. We also applied the chi-square test to investigate responses to the five ordered Likert items. The null hypothesis in this study is that there is no significant difference between the socioeconomic profile of HFCV adopters and non-adopters, and that HFCV adopters who leased HFCVs might have a different profile than those who bought. Another hypothesis in our study is that profile of private HFCV adopters follows the profile of the early adopters mentioned in the "Diffusion of Innovations" theory by EM Rogers [17].

The next section – results and discussions is organized as follows. Firstly, we present the socio-economic profile of the sample population of the current study in Table 2 following summary Table 3 showing characteristics of the recent surveys carried out to examining company HFCV adopters in the Aichi Prefectural region. Secondly, in the sub-section 4.1, we compare the characteristics of the current survey with the potential car buyer survey, whereas sub-section 4.2 presents the comparison of the current survey with the company early adopter survey. Finally, in the next sub-sections 4.3 & 4.4, we explore different segments of the private early adopter survey.

4. Results and discussions

Table 2 presents the basic demographic characteristics of the respondents. Male respondents dominate the sample by almost 90%. The age groups of respondents ranging between 20 and 49 years and 50 and above were approximately 16% and 84%, respectively. According to the Japanese Population Survey administered by the Statistics Bureau in 2015, 45.7% of the population were aged 50 and above [86]. Table 2 also shows the highest level of education achieved by the HFCV adopters and household income of the study participants. The average household income in our sample is ¥9,000,000 (US $85,000), which is almost double the national average [87]. Most of the respondents in this sample own homes (89%), with only 11% renting. The ownership rate is slightly higher in our sample when compared with the national average of 62% [87]. 78% of the sample population live in a detached single-family home, with only 22% living in an apartment building. The average number of people in the household is 2.70 against 2.33 of the national average in 2015 [88]. This is in line with the Japanese Bureau of Statistics estimations, which expected an increase in the average household size until 2023 and then declined. In our sample, the average number of vehicles in our sample is 2.4 against 1.65 in Aichi Prefecture [89]. As illustrated, our sample has more males than females, has a significantly older population, has a high school or higher education level, and has higher income levels than the national average. Accordingly, our sample does not entirely represent the socioeconomic characteristics of the general population in Japan, and the relatively small sample size makes it a non-viable representation of the population, but it may be proportionately representative of the rest of the private HFCV adopters in Japan.

Table 2. Socioeconomic profile of the private HFCV adopters.

Characteristics		Private HFCV adopters	
		n	%
Sex	Female	9	10.1
	Male	80	89.9
Age	20s	2	2.3
	30s	4	4.6
	40s	8	8.9
	50s	25	28.1
	60s	27	30.3
	70s and above	23	25.8
Household income	Less than ¥ 3 (M)	3	3.4

	¥ 3 - 4.99 (M)	6	6.7
	¥ 5 - 6.99 (M)	18	20.2
	¥ 7 - 8.99 (M)	10	11.2
	¥ 9 - 10.99 (M)	21	23.6
	¥ 11 - 12.99 (M)	8	9.0
	¥ 13 - 14.99 (M)	2	2.3
	¥ 15 - 16.99 (M)	2	2.3
	¥ 17 (M) or more	12	13.5
Highest level of education completed	Junior high school	4	4.5
	Senior high school	32	36.0
	Technical college	13	14.6
	Undergraduate degree	37	41.6
	Graduate degree	3	3.4
Residence ownership status	Own	79	88.8
	Rent	8	9.0
Residence type	Detached	69	77.5
	Attached	0	0.0
	Apartment building	18	20.2
Number of people per household	1	10	11.2
	2	33	37.1
	3	24	27.0
	4	12	13.5
	5 or more	9	10.1
Number of household vehicles	1	12	13.5
	2	43	48.3
	3	21	23.6
	4 or more	13	14.6
Previous AFV experience	BEV	6	6.7
	PHEV	7	9.0
	HV	59	66.3
	None	22	24.7

Table 3 summarizes the basic characteristics of the recently conducted surveys in Aichi Prefecture to investigate consumers' knowledge, awareness, and perception of hydrogen vehicles and related infrastructure. Potential car buyer survey included detailed information on socioeconomic characteristics such as age, income, highest education level, number of people in the household, job status, travel patterns, trip purpose, questions on HFCVs, and reasons for buying a car. Recently, the Environmental Bureau Division of the Aichi Prefectural Government implemented a questionnaire survey, from December 2019 to January 2020, exploring residents' willingness to adopt green fuel vehicles (BEV, PHEV, HFCV), degree of awareness, and satisfaction levels with the HFCVs and the related charging infrastructure. The sample population was recruited using an Internet survey and the distribution of questionnaires by mail. A total of 249 HFCV holders of small and medium-sized enterprises were included in this survey.

Table 3. Basic characteristics of the recent surveys in Aichi Prefecture, Japan.

	Potential car buyer survey	Company early adopter survey	Private early adopter survey (current survey)
Survey Year	2018	2020	2020-21
Administering authority	Nagoya University	Aichi Prefectural Government	Nagoya University, ENEOS, Toho Gas, Toyota City Government
Sampling method	Purposive sampling	Purposive sampling	Purposive sampling
Vehicle status	HFCV non-adopters	HFCV adopters	HFCV adopters
HFCV ownership status	N/A	Company cars	Privately owned
N	500 (32 potential HFCV adopters)	216	89
Percentage of female	46.88	N/A	10.11

For better understanding from the user's perspective, hereinafter, we will use the terms the car buyer, the company adopter, and the private adopter presenting samples at potential car buyer survey, company early adopter survey, and private early adopter survey, respectively. Private adopters currently own HFCVs comparing to company adopters who are currently adopting HFCVs as a company car, whereas car buyers are not adopting HFCVs, currently.

4.1. Comparison between the car buyers and the private adopters

4.1.1. Socioeconomic profile

When compared with the car buyers who are also the non-adopters of HFCVs, the sample population of the current study, the private adopters, depicts some distinctive features. The average household income of our current sample is more than double that reported in 2018. The current sample is dominated by the age group 50 and above (85%) compared to the earlier sample having 78.13% between 17 and 54. The number of female respondents in the earlier sample (46.88%) was also more than three times. The number of vehicles per household in the current sample population is 2.4, which is higher than the 2018 sample average of 1.7. In the 2018 sample, the mean household size was 3.03 against 2.7 of the current sample. In addition, 9.38% of HFCV non-adopters had previously experienced BEV compared to 6.74% of the current sample.

Table 4 presents chi-square test results comparing the gender, education, previous PHEV/HV experience, and BEV experience of HFCV adopters and non-adopters. Significant differences arise because most of the HFCV adopters are male, have higher education levels, and have previously experienced more hybrid vehicles than BEVs. Compared with 16.6% of the non-adopters, 66% of the HFCV adopters have previous experience using hybrids. This agrees with studies on BEV adoption indicating younger households are more willing to adopt BEVs [90–93]. Our sample population for the current study is dominated by households in their 50s and above. Since the introduction of the first-ever mass-produced hybrid car in 1997, these vehicles broke through in the Japanese auto-market with the highest penetration rate worldwide [94].

Table 4. Pearson's chi-square results comparing differences between the private HFCV adopters and non-adopters.

Variable	N	df	chi-square	p-value
Gender	589	1	22.50	<0.01***
Education	589	1	104.88	<0.01***
HVs experience	589	1	102.51	<0.01***
BEV experience	589	1	09.06	<0.01***

Significance: *p<0.1, **p<0.05, ***p<0.01

Table 5 shows the results of the t-test comparing the means of age, household size, household income, and number of vehicles of HFCV adopters and non-adopters. This investigation reveals that the null hypothesis of there being no difference between the expected and observed frequencies between the groups can be rejected for household income, age, number of people in the household, and number of vehicles. Some of the earlier studies on fuel-cell vehicle adopters also indicated that high-income households are more likely to adopt fuel-cell vehicles [16,63–69]. In our sample, people aged 50 and above are keener on adopting hydrogen vehicles, which contradicts earlier studies stating higher interest and intention of younger people in adopting new technology vehicles [9,69,95–98].

Table 5. T-test results comparing the mean socioeconomic status between the private HFCV adopters and non-adopters

Variable		Group	N	std. Dev	mean	t-ratio	p-value
Socioeconomic status	Household income	HFCV adopters	89	4,457,805	9,630,988	-3.67	<0.01***
		Non-adopters	500	4,188,606	7,684,170		
	Age	HFCV adopters	89	12.29	60.68	-11.89	<0.01***
		Non-adopters	500	12.97	43.62		
	Household size	HFCV adopters	89	1.15	2.74	2.12	0.03**
		Non-adopters	500	1.29	3.03		
	Number of vehicles	HFCV adopters	89	0.88	2.40	2.95	<0.01***
		Non-adopters	500	0.87	2.68		

Significance: *p<0.1, **p<0.05, ***p<0.01

4.1.2. Reasons for car purchase and previous knowledge on HFCVs

Table 6 presents the cross tabulations between the two groups on reasons for a car purchase and knowledge of hydrogen vehicles. Respondents provided categorical information on the type of hydrogen-related knowledge and reasons for car purchase.

Table 6. Cross tabulations on reasons for car purchase and knowledge on hydrogen vehicles between the private HFCV adopters and non-adopters[a].

Characteristics	Category	HFCV adopters		Non-adopters	
		n	%	n	%
Reasons for car purchase	Random replacement of vehicle	35	39.8	238	47.6

	Previous vehicles getting old	25	28.4	274	54.8
	Interest in new fuel technology	66	75.0	55	11.0
	Looking for vehicle with good mileage	6	6.8	78	15.6
	Looking for vehicle with zero carbon emissions	21	23.7	12	2.4
Knowledge on hydrogen vehicles	Hydrogen as an alternative fuel technology	69	78.4	213	42.6
	HFCV purchase price	63	71.6	143	28.6
	HFCV driving range/mileage	55	62.5	159	31.8
	Governmental incentives on the purchase	72	81.8	142	28.4
	Hydrogen refueling stations	61	69.3	218	43.6

[a] Multiple answers are allowed

Table 7 summarizes the chi-square test results comparing the differences between the private HFCV adopters and non-adopters on the reasons for car purchases. The results of this investigation show that the null hypothesis of there being no difference between the expected and observed frequencies between the two groups can be rejected for variables on previous vehicles getting old, interest in new fuel technology, vehicle with good mileage, and zero carbon emissions at the 0.01 significance level. Approximately 75% of the HFCV adopters showed interest in new vehicle technology compared to mere 11% of non-adopters. More HFCV adopters were interested in vehicles with zero carbon emissions than non-adopters. Some of the earlier studies correlate the profile of environmentally friendly vehicles with high environmental consciousness [16,65,99–102]. In contrast, Orlov and Kallbekken [103], in their empirical study in Norway, found no significant relationship between environmental concern and car choice.

Table 7. Pearson's chi-square test results comparing differences between the private HFCV adopters and non-adopters on reasons for a purchase.

Variable	N	df	chi-square	p-value
Random replacement of vehicle	589	1	1.84	0.17
Previous vehicles getting old	589	1	20.85	<0.01***
Interest in new fuel technology	589	1	187.54	<0.01***
Looking for vehicle with good mileage	589	1	4.71	0.02**
Looking for vehicle with zero carbon emissions	589	1	65.07	<0.01***

Table 8 summarizes the chi-square test results comparing differences between the private HFCV adopters and non-adopters. As expected, we found a significant difference at the 99% confidence interval between the two groups considering that HFCV adopters have more knowledge on different aspects of HFCVs, such as purchase price, driving range, available governmental incentive, and hydrogen stations networks.

Table 8. Pearson's chi-square test results comparing differences between the private HFCV adopters and non-adopters on knowledge of HFCVs.

Variable	N	df	chi-square	p-value

Hydrogen as an alternative fuel technology	589	1	38.45	<0.01***
HFCV purchase price	589	1	60.76	<0.01***
HFCV driving range/mileage	589	1	30.46	<0.01***
Governmental incentives on the purchase	589	1	92.24	<0.01***
Hydrogen refueling stations	589	1	19.85	<0.01***

Significance: *p<0.1, **p<0.05, ***p<0.01

4.2. Comparison between the private adopters and the company adopters

4.2.1. Attitudes toward HFCVs

It is crucial to investigate the difference between the private adopters with HFCV ownerships and the company car adopters without ownership. We compared the responses of the private adopters and the company adopters. The results are shown in Fig. 2. In both questionnaires, HFCV adopters were asked to indicate the degree of satisfaction with a Likert-item type question (where 1=strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) to evaluate several important HFCV-related characteristics such as purchase price, environmental performance, driving range, refueling time, refueling infrastructure, and vehicle performance.

About 70% of the private adopters were highly dissatisfied with the current status of hydrogen refueling stations, compared to 76% for the company adopters. As expected, more than 80% of the respondents in both surveys were either satisfied or very satisfied with the environmental performance of the vehicle. In contrast, around 72% of the private adopters were not satisfied with the driving range of HFCVs compared to 52% of the company adopters. The negative response rate on the driving range can be due to the low mileage (312 miles) of the first-generation HFCV compared to the most successful versions of the hybrid vehicles, “Toyota Prius,” having a mileage of 640 miles. Regarding the purchase price factor, around 40% of the private adopters were not satisfied compared to 25% of the company adopters. Around half of the participants in both surveys were satisfied/very satisfied with the refueling time.

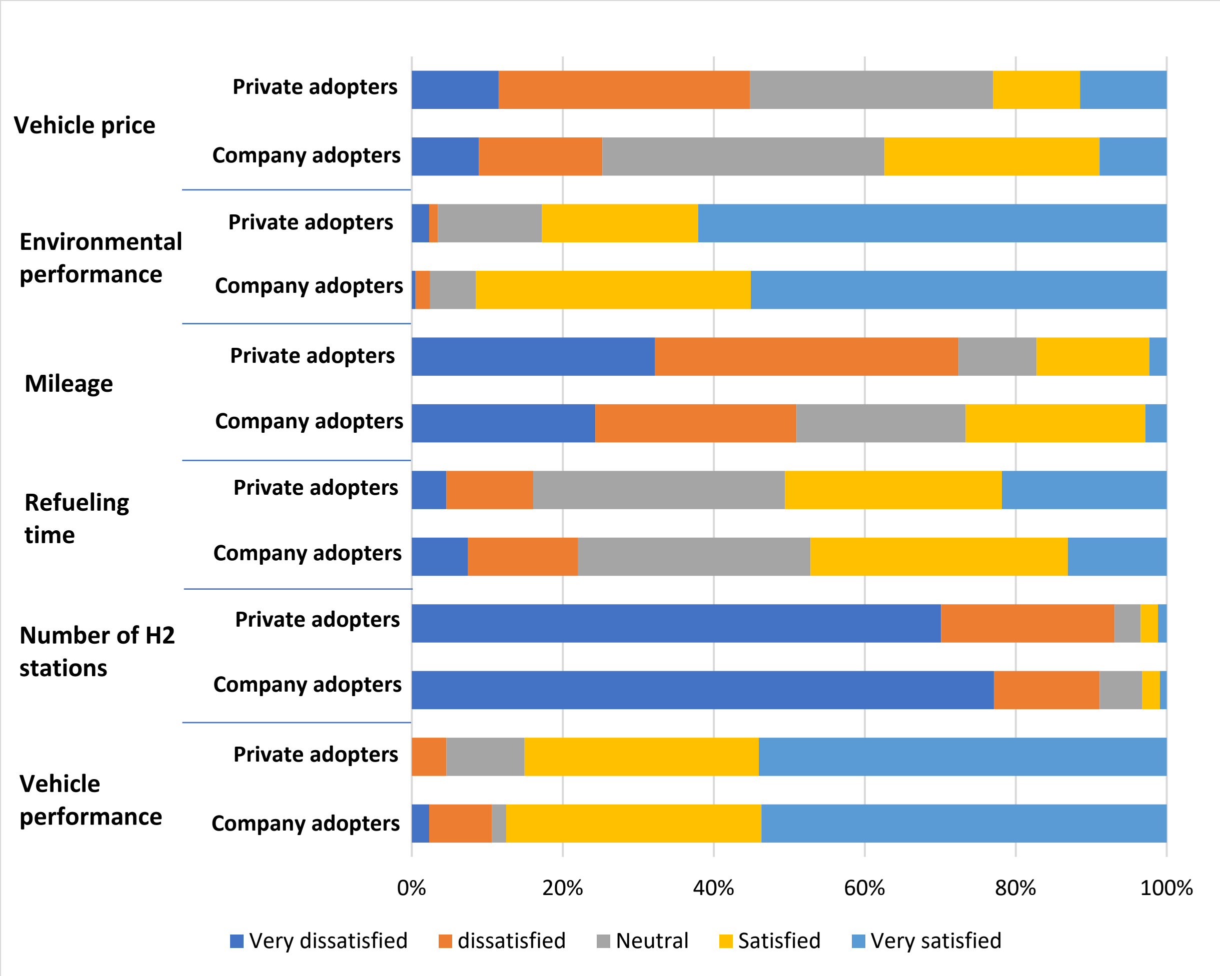

Fig. 2 Percentage of the private and company HFCV adopters' attitude toward hydrogen vehicle attributes

Around 50% of the private HFCV adopters preferred replacing current hydrogen vehicles compared to 37% of the company HFCV adopters (Fig. 3). Extensive research studies have been carried out in understanding the factors that influence adoption either by investigating profile of the early adopters or through stated choice experiments [8-10,14,38,40,42,44-47,49-50]. Despite extensive developments in the diffusion policies that boost growth in the adoption of these green fuel vehicles, there is less clear indication that they have successfully promoted the diffusion of HFCVs comparing to adoption of BEVs and HVs.

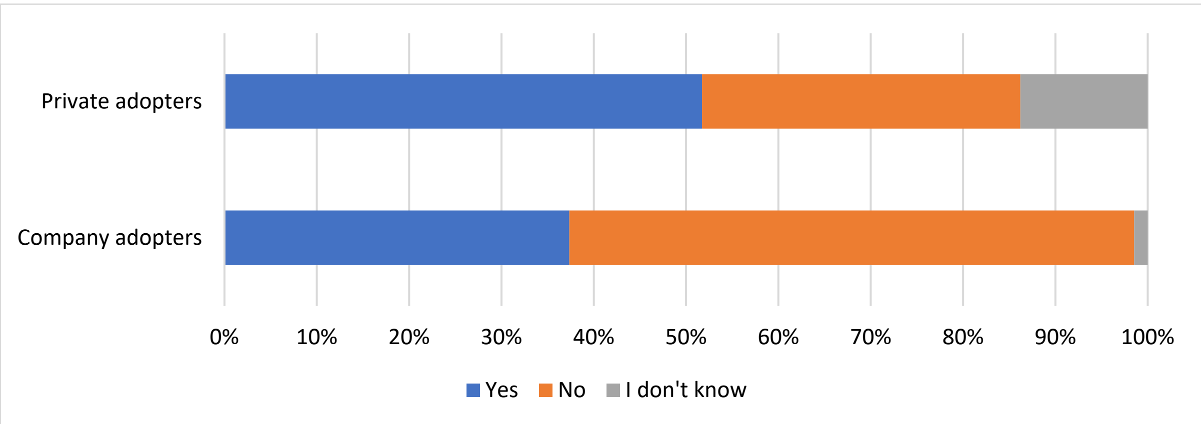

Fig. 3 Response percentage of the private HFCV adopters and the company adopters when asked, “Would you replace your current vehicle fuel technology?”.

Figure 4 shows the response count for the private adopters’ reason for replacing the current HFCV. As expected, the lack of refueling stations and limited station business hours are the most critical factors, with others being purchase price, safety, maintenance cost, and vehicle performance. Currently, hydrogen refueling stations in Japan operate over a fixed period from 09:00 AM to 05:00 PM. During the operational hours, trained station staff refuel the hydrogen fuel tank on behalf of the customers. This highlights the biggest impediment to the successful rollout of HFCVs in Japan. A limited station network with fixed timing impacts consumers’ sentiments. Recent studies have correlated the difficulties in HFCV proliferation with the lack of refueling infrastructure [16,65,104–108].

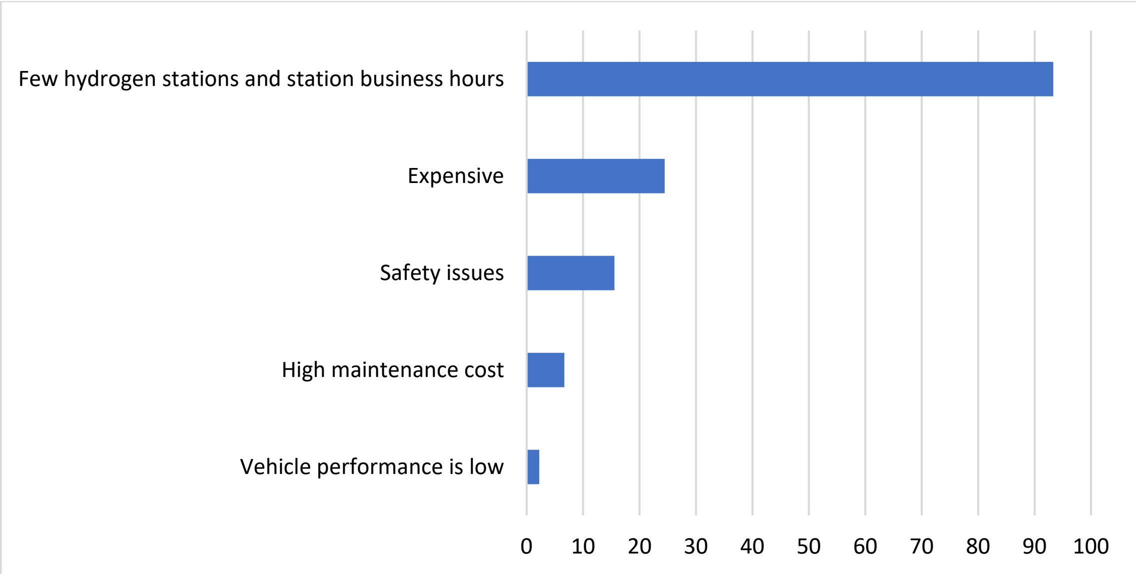

Fig. 4 Percentage of the private adopters who will replace HFCV when inquired, “What is the reason of replacing current HFCV?”.

4.2.2. Access to nearby hydrogen refueling stations

Figure 5 displays the time required to reach the nearest hydrogen refueling station by both groups. Compared to the company adopters, more than 60% of the private adopters had access to nearby hydrogen refueling statons within 10 to 15 minutes of driving time. In their empirical study, Brey et al. [109] mentioned the correlation between the time to reach the nearby fuel station and the driver acceptance rate. More than 89% of the drivers were willing to accept the alternative fuel vehicle if the refueling station was in the range of 5 to 10 minutes.

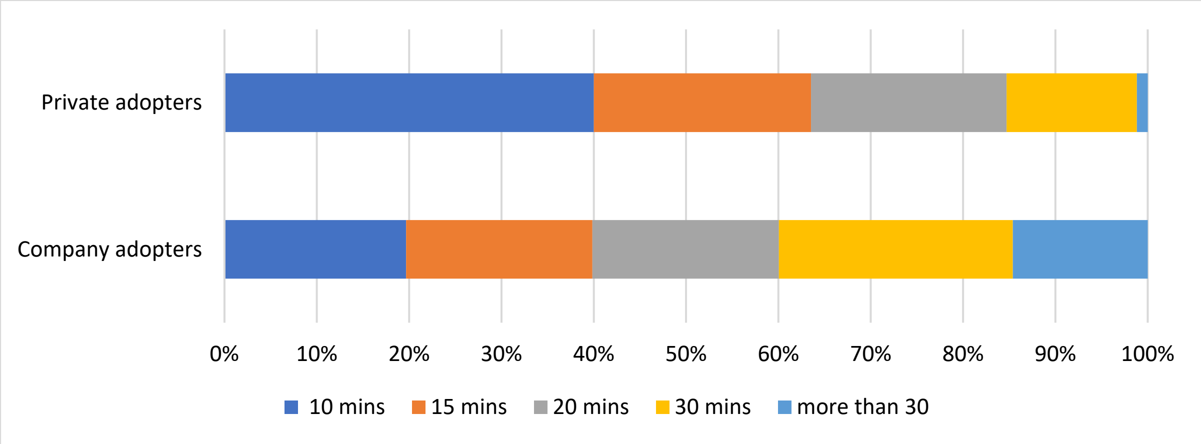

Fig. 5 Percentage driving time of the private HFCV adopters and the company adopters to frequently used HFCV refueling stations

4.3. Exploring HFCV ownership status – the private adopters

Figure 6 shows the sample distribution between those who leased and bought HFCVs. As stated in Data and methodology section, respondents were recruited via two modes, and one of them was through Toyota City Government to the residents who applied for the incentives to purchase HFCV. Thus, the sample share becomes biased to those who bought. Excluding them make a share of only 22% who bought compared to 78% who were leasing. It means the leasing is dominant for the private early adopters. However, as shown in the appendix (Table A.3), we find no statistical difference in the socioeconomic status between the two groups, that is, adopters who leased or bought HFCVs.

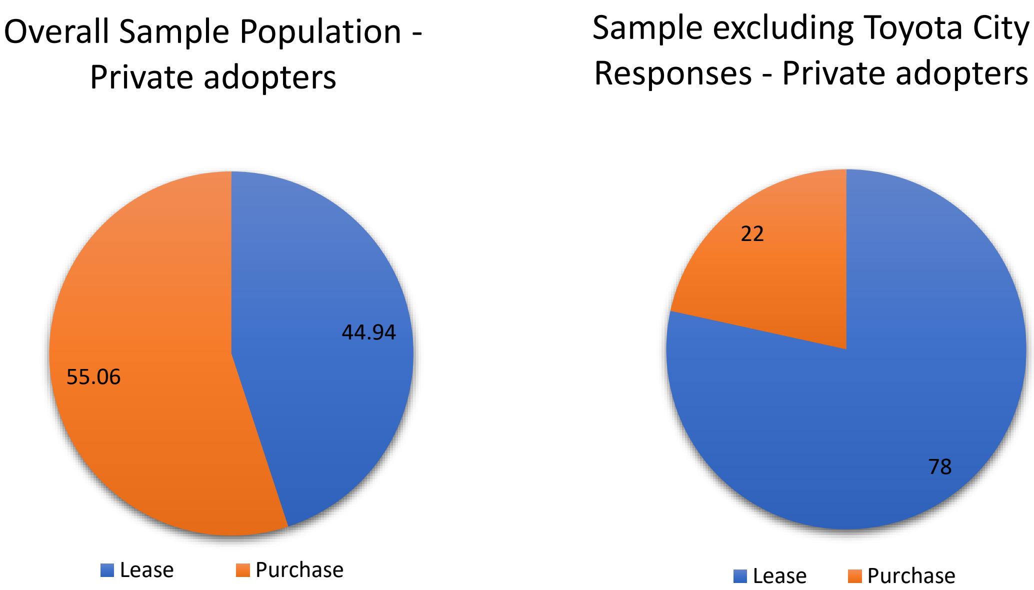

Fig. 6 Percentage of the private HFCV adopters who leased and bought HFCVs.

Table 9 summarizes the chi-square test results between the two groups on the degree of satisfaction (1=strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) for several HFCV and infrastructure-related characteristics. Firstly, we did the analysis on five different satisfaction levels, the null hypothesis that there is no difference between the groups can be rejected for governmental incentives at a 99% confidence interval and number of hydrogen refueling stations at the 0.1

significance level. These differences are due to the higher dissatisfaction level of the adopter group who are leasing on the currently available governmental incentives, and number of hydrogen stations.

Table 9. Pearson's chi-square test results comparing differences between HFCV adopters who leased and purchased HFCVs and their degree of satisfaction related to HFCVs.

Factors	N	chi-square	df	p-value
Purchase price	89	0.20	1	0.65
Refueling time	89	0.60	1	0.44
Maintenance cost	89	0.98	1	0.32
Driving range/mileage	89	0.28	1	0.59
Vehicle performance	89	0.59	1	0.44
Fuel economy	89	0.02	1	0.88
Governmental incentives	89	11.00	1	<0.001***
Environmental impact	89	0.37	1	0.54
Power supply function	89	0.29	1	0.59
Hydrogen tank safety performance	89	0.00	1	0.97
Incentive/discount on purchase	89	0.87	1	0.34
Comparison with latest fuel technologies	89	0.75	1	0.38
Car image/looks	89	0.00	1	0.97
Car brand (manufacturer-Toyota/Honda)	89	0.40	1	0.52
Future viability/car of the future	89	0.01	1	0.89
Using hydrogen as a fuel	89	1.53	1	0.22
Number of hydrogen stations	89	2.60	1	0.10*

Significance: *p<0.1, **p<0.05, ***p<0.01

4.4. Factors influencing purchase of HFCVs

Respondents in our study were asked to choose the degree of importance of a given set of factors that determine the purchase of HFCVs. Table 10 summarizes the response percentage (where 1=not at all, 2 = unimportant, 3 = a little, 4 = a lot, 5 = predominant) on HFCV attributes and incentives. Except for tax incentives, all other incentives in our questionnaire are hypothesized for future hydrogen vehicle purchases. The percentage of respondents selected either a level 4 or 5 degrees of importance is listed in Table 11.

Vehicle-related factors, such as the number of hydrogen refueling stations, hydrogen fuel tank safety features, and zero-emission feature of HFCVs are stated to have the highest degree of importance at 93.1%, 84.1%, and 84.1%, respectively. Interestingly, the study conducted by Hardman and Tal [16] also highlighted the lack of hydrogen refueling infrastructure in California as a barrier to the successful proliferation of HFCVs. However, only 75% of the HFCV adopters in the study by Jaramillio et al. [64] discussed the zero-emission feature of HFCVs. Other factors most frequently reported as important (those stated level 4 or 5 degrees of importance) by more than 70% of the respondents are related to hydrogen vehicle driving range compared to traditional fossil fuel-based vehicles following BEVs and PHEV/HVs. Respondents also gave weight to vehicle performance in terms of power and acceleration at 70.45%. In a study undertaken by Jaramillo et al. [64], 100% of the respondents reported a lack of refueling infrastructure and other factors such as purchase price and comparison with other fuel technologies. Contrary to this, in our study, respondents stated a lower degree of importance to HFCV purchases.

The three most frequently stated incentives are (i) tax incentives on the purchase of HFCV, (ii) free hydrogen fuel for three years, and (iii) free toll on expressways for five years. Currently, only financial incentives (worth ¥1.4 million (USD 13,000) by the national government and additionally by the local government at some cities) are available on the purchase of HFCVs, and financial incentives substantially impact motivation than non-financial incentives.

Table 10. Degree of the importance of factors determining the purchase of hydrogen fuel vehicles.

Purchase factors	Degree of importance (%)				
	1 not at all	2 unimportant	3 a little	4 a lot	5 predominant
It emits no greenhouse gas emissions	2.3	4.5	9.1	26.1	57.9
Performance (such as power, and acceleration)	2.3	9.1	18.2	39.8	30.7
Time it takes to refuel	0.0	12.5	27.3	34.1	26.1
HFCV purchase price relative to CV	0.0	8.1	22.1	37.2	32.6
HFCV purchase price relative to BEV	2.3	3.4	32.9	30.7	30.7
HFCV purchase price relative to PHEV/HV	2.3	7.9	27.3	32.9	29.5
Driving range compared to CV	1.1	4.5	14.8	42.1	37.5
Driving range compared to BEV	1.1	5.8	19.5	37.9	35.6
Driving range compared to PHEV/HV	4.6	3.5	20.7	36.8	34.5
Power supply function	3.4	11.4	42.1	31.8	11.4
Hydrogen tanks safety features	1.1	1.1	13.6	27.3	56.8
Number of hydrogen refueling stations	1.1	2.3	3.4	18.4	74.7

Table 11. Degree of importance (level 4 or 5) of factors determining the purchase of HFCV and governmental incentives.

Factor	Percentage(%)
Number of hydrogen refueling stations	93.1
Hydrogen fuel tank safety features	84.1
Feature of emitting no greenhouse gases	84.1
Hydrogen vehicle driving range compared to conventional vehicle	79.6
Hydrogen vehicle driving range compared to battery electric vehicle	73.6
Driving range compared to plug-in-hybrid electric vehicle/hybrid vehicle	71.3
Hydrogen vehicle performance such as power, acceleration etc.	70.5
Hydrogen vehicle purchase price relative to conventional vehicle	69.8
Hydrogen vehicle purchase price relative to plug-in-hybrid electric vehicle/hybrid vehicle	62.5
Hydrogen vehicle purchase price relative to Battery electric vehicle	61.4
Time it takes to refuel	60.2
Power supply function in the case of emergency/disaster	43.2
Incentives	
Tax incentives on owning or buying a car	94.3
Free hydrogen fuel for three years	88.5

Free toll on expressways for five years	86.4
Free public parking for five years	72.4
Free public transport on weekend for five years	62.9

5. Conclusion and policy implications

This study attempts to explore the experiences of private households with HFCVs. We collected data from different hydrogen refueling stations in Aichi Prefecture, Japan and Toyota City residents who applied local governmental incentives to purchase HFCVs. The survey was conducted between November 2020 and January 2021. The core sample population comprises private users of HFCVs. Currently, there are around 4,000 HFCVs running on Japanese roads, most of which are owned by either government or private corporations associated with the Japan Hydrogen Association. Few of these vehicles are owned by private households, who are highly educated, earn a high income, have previously experienced AFVs, and are environmentally conscious. Current HFCV households reported that limited hydrogen stations and station business hours halted travel plans. To understand the variance in the responses, we compared the results of the current survey with that conducted by Nagoya University and Aichi Prefectural Government in 2018 and 2020, respectively. Table 12 summarizes the outcomes of the hypotheses tested in this study.

Table 12. Summary of hypothesis testing

Hypothesis	Verification results
H1: There is no significant difference between socio-economic profile of HFCV adopters and non-adopters	Do not support
H2: HFCV adopters who leased their HFCVs might have a different profile than those who bought	Partially support
H3: Profile of private HFCV adopters is similar to characteristics of the early adopters mentioned by EM Rogers	Partially support

Existing studies on HFCVs in the Japanese market does not examine private households owning HFCVs [42,74-81]. From the broader HFCV literature, a few real-world studies have been conducted on a sample population of privately owned HFCVs. This is a significant research gap that this study seeks to fill. HFCV adopters highlighted the need to expand the current refueling station network and increase station operational hours. In Japan, most of the hydrogen stations are operational during the daytime for 8 h (09:00 AM to 05:00 PM). From a safety perspective, hydrogen stations in Japan are manned by trained employees who refuel vehicles on behalf of customers. Previously, fire incidents at hydrogen stations in Norway and South Korea have hampered consumers' motivation to adopt these vehicles. Japan has not observed any safety incidents and has successfully gained consumers' trust from the hydrogen fuel's safety outlook.

Comparing to HFCV studies conducted in other markets outside Japan, our study provides interesting insights, some of which are not aligned with the outcome of those studies conducted in Europe and US. Earlier studies highlighted that younger households are more likely to buy green fuel vehicles [42,47,64,81,98,110-112]; but our study does not reflect the fact that younger adults (20s and 40s) are more likely to adopt new fuel technologies than the older households (50s and above). One reason of this difference can be linked to the stronger financial position of the elderly in Japan. Considering the fact that HFCV comes with a high-price tag of nearly ¥7 million without subsidies that makes it difficult for the younger households to adopt. According to the government white paper on aging society released in 2019, the older respondents were found to be financially stable than the younger households in their 40s [113]. Interestingly, households who discontinued using PHEVs in California were younger people with lower incomes [114]. Households who are currently adopting their HFCVs in our sample are older with higher incomes. In the study by Jenn et al. [110], PHEV owners showed their intention to continue using PHEVs with the availability of incentives which is contrary to preferences of HFCV households in our sample.

The focus of this study was to investigate private adopters of HFCVs to identify experiences and challenges. A significant proportion of the respondents were not satisfied with the current status of hydrogen refueling stations and the station timings. More than 50% of the respondents were willing to replace their current HFCVs due to these bottlenecks. The discontinuity in using the current green fuel vehicle has been observed not only in Japan but also in other major markets – California. A study by Hardman and Tal [114] highlighted that nearly 18% of BEV households and 20% of PHEV households discontinued the ownership of these green fuel vehicles between the years 2015 and 2019. A significant barrier in causing this change was reportedly the different refueling style from the traditional fuel vehicles. The determinants of discontinuous intention in our study are not significantly correlated with the price, safety issues, high maintenance cost, or vehicle performance but rather with the limited stations network and station business hours. None of the earlier studies in Japan or elsewhere highlight hydrogen station business timings-related barrier as one of the significant factors in Japanese respondents' decision to replace their current HFCVs. This is a particular example applicable in the Japanese market only, where hydrogen refueling stations operate during limited hours on the week days. From this study, we assume that the initial purchase of HFCV is occurring concurrently along with other powertrains in the Japanese market but with more HFCV private adopters reporting they would like to discontinue the ownership of HFCVs due to hydrogen refueling stations-related barriers.

The satisfactions by the private adopters to HFCV performances were almost similar to those by the company adopters in the survey administered by the Aichi Prefectural Government. However, the private adopters in our sample have higher socioeconomic status, are mostly male, in their 50s and above, highly educated, with high interest in new fuel technology, and have more knowledge of HFCVs and related information than non-adopters.

Although Japan has led the world in the race to commercialize hydrogen and its applications in different sectors, opportunities for Japanese respondents to see HFCVs outside the prefectures with few hydrogen stations remain limited. Though Toyota Motor Corporation celebrated the 10,000th copy of its HFCV "Mirai" in September 2019, there are only 1,136 registered HFCVs and 27 hydrogen refueling stations in the Aichi Prefecture as of 2020. Several registered HFCVs are owned by different associated companies advocating a hydrogen-powered society. The trend in HFCV sales in Japan is shown in Fig. 7. The current economic circumstances and drop in household consumption following the COVID-19 pandemic and related lockdowns may affect the HFCV sales target set by the Japanese government. As the world's third-largest economy rebounded from the record slump due to the global pandemic in the last quarter of 2020, the hydrogen sector has experienced new developments and turnaround. For the first two months in 2021, HFCV sales hit the highest level on record since the first commercial debut of the vehicle in 2014. The sharp rise in sales can also be attributed to the launch of the second-generation HFCV Toyota Mirai 2021, which has salient features over its previous variant. In 2021, the ground-breaking ceremony of the so-called "Woven City" was held in the outskirts of Mount Fuji, to see the use of hydrogen in a real-world environment.

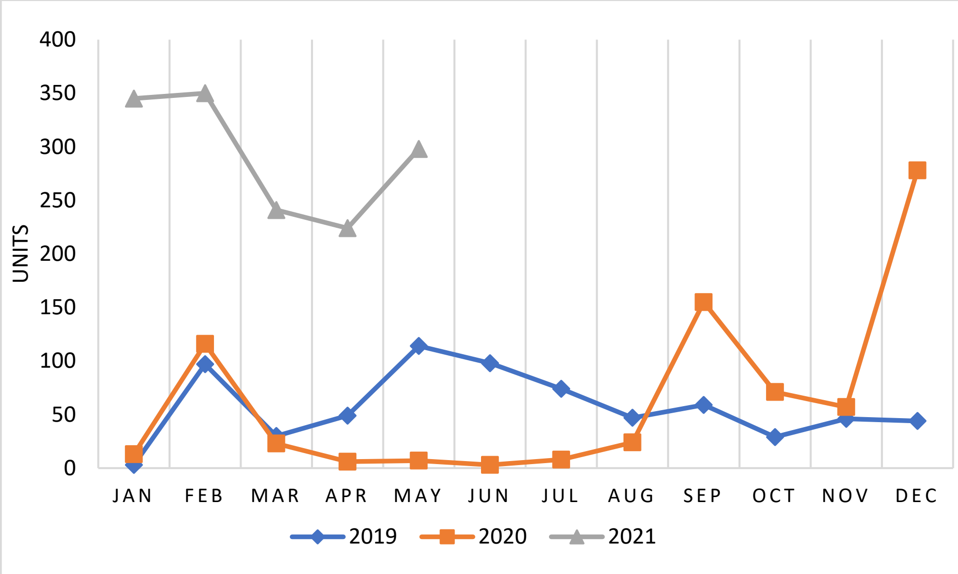

Fig. 7 Trend in HFCV sales

The Japanese government is keen to adopt hydrogen as an alternative to nuclear and fossil fuel energy to realize zero net carbon emissions by 2050. Comparing to Japan, China is focusing on the development of hydrogen-powered trucks considering the fact that heavy-duty trucks are the main source of emitting greenhouse gas emissions in the transportation fleet [115]. Despite the government subsidy of more than one million yen ($10,000) on each HFCV unit, the hefty price tag of ¥5.6 million ($55,000) after subsidy still impedes the successful commercial diffusion of these vehicles. Even though Japan has the largest hydrogen refueling stations network in the world, it is still facing difficulties in the successful diffusion of these zero-emission vehicles. The government is still optimistic that in the coming years, they can bring down the cost difference between HFCV and HVs to ¥0.7 M from ¥3 M. One of the key outcomes of the study by Bethoux [116] is that the beginning of the large-scale commercial rollout of HFCVs will begin by 2030-2035. Yet, it is still unclear to what extent HFCVs will successfully be able to penetrate into the automotive market driven by rapid growth in the BEV/PHEV sales.

Japan's infatuation with HFCVs and related applications continue, and proponents are yet to see the successful adoption of these green vehicles. Given the current scenario, policymakers must consider the concerns of the current HFCV adopters, especially the need to extend the refueling station business hours. Although hydrogen vehicles still make a niche segment in the Japanese auto-market, the government and associated companies backing the realization of the world's first hydrogen society should address the concerns of HFCV owners.

5.1. Limitations

This research focuses only on HFCV adopters in the Aichi Prefecture region, resulting in a very small sample size of the private HFCV adopters. Secondly, the sample being undoubtedly having more positive inclination towards HFCVs due to the specific methods used in finding the sample. This study also did not consider the stakeholders' opinions who are advocating for the concept of a hydrogen society and are heavily financing hydrogen-related infrastructure throughout the country.

5.2. Future research

Future research should look ways to gather large sample size in an attempt to have more reliable outcome with greater precision and power. One way is to involve private stakeholders of the hydrogen-related business in Japan. Future research should collect data from the Greater Tokyo and Kyushu regions in Japan, as these regions, along with Aichi Prefecture, share the highest number of hydrogen vehicles and refueling stations in Japan. The next study can be conducted in association with the Japan Hydrogen Association representatives, Toyota Motor Corporation, Ministry of Energy, Trade, and Industry, and Toyota City Government. We are also considering carrying out study on the relationship between the governmental incentives available in various towns/city governments in Aichi Prefecture and the number of hydrogen refueling stations. The outcome should reflect the differences and similarities between the attitudes of the private HFCV adopters in all major regions with dense network of hydrogen refueling stations in Japan. The policy implications from this type of study will assist in fully understanding the behavioral gaps between the consumers using HFCVs and policymakers trying to proliferate these zero-emission vehicles in Japan.

Acknowledgments

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Appendix

Table A.1. Socioeconomic profile of the potential car buyers.

Characteristics		HFCV non-adopters n	HFCV non-adopters %
Sex	Female	179	35.8
	Male	321	64.2
Age	20s	99	19.8
	30s	113	22.6
	40s	118	23.6
	50s	89	17.8
	60s	81	16.2
	70s and above	0	0.0
Household income	Less than ¥ 3(M)	53	10.6
	¥ 3 - 4.99 (M)	80	16.0
	¥ 5 - 6.99 (M)	113	22.6
	¥ 7 - 8.99 (M)	109	21.8
	¥ 9 - 10.99 (M)	40	8.0
	¥ 11 - 12.99 (M)	45	9.0
	¥ 13 - 14.99 (M)	26	5.2
	¥ 15 - 16.99 (M)	11	2.2
	¥ 17 (M) or more	23	4.6
Highest level of education completed	Junior high school	8	1.6
	Senior high school	113	22.6
	Technical college	50	10.0
	Undergraduate degree	262	52.4

	Graduate degree	56	11.2
Number of people per household	1	67	13.4
	2	115	23.0
	3	126	25.2
	4	136	27.2
	5 or more	56	11.2
Number of household vehicles	1	222	44.4
	2	184	36.8
	3	55	11.0
	4 or more	21	4.2
Previous AFV experience	BEV	3	0.6
	HVs	83	16.6

Table A.3. Distribution of socioeconomic profile of the private HFCV adopters who bought and leased HFCVs.

Characteristics		Private HFCV adopters			
		Bought		Leased	
		n	%	n	%
Sex	Female	6	12.2	3	7.5
	Male	43	87.8	37	92.5
Age	20s	1	2.0	1	2.5
	30s	2	4.1	2	5.0
	40s	4	8.2	4	10.0
	50s	17	34.7	8	20.0
	60s	14	28.6	13	32.5
	70s and above	11	22.5	12	30.0
Household income	Less than ¥ 3 (M)	3	6.1	0	0.0
	¥ 3 - 4.99 (M)	4	8.2	2	5.0
	¥ 5 - 6.99 (M)	10	20.4	8	20.0
	¥ 7 - 8.99 (M)	3	6.1	7	17.5
	¥ 9 - 10.99 (M)	15	30.6	6	15.0
	¥ 11 - 12.99 (M)	4	8.2	4	10.0
	¥ 13 - 14.99 (M)	1	2.0	1	2.5
	¥ 15 - 16.99 (M)	1	2.0	1	2.5
	¥ 17 (M) or more	6	12.2	6	15.0
Highest level of education completed	Junior high school	2	4.1	2	5.0
	Senior high school	18	36.7	14	35.0
	Technical college	6	12.2	7	17.5
	Undergraduate degree	20	40.8	17	42.5
	Graduate degree	3	6.1	0	0.0
Residence ownership status	Own	45	91.8	34	85.0

	Rent	4	8.2	5	12.5
Residence type	Detached	39	79.6	30	75.0
	Attached	0	0.0	0	0.0
	Apartment building	10	20.4	8	20.0
Number of people per household	1	7	14.3	4	10.0
	2	15	30.6	18	45.0
	3	14	28.6	10	25.0
	4	7	14.3	5	12.5
	5 or more	6	12.2	3	7.5
Number of household vehicles	1	5	10.2	7	17.5
	2	21	42.9	22	55.0
	3	14	28.6	7	17.5
	4 or more	9	18.4	4	10.0
Previous AFV experience	BEV	2	4.1	4	10.0
	PHEV	6	12.2	2	5.0
	HV	34	69.4	25	62.5
	None	10	20.4	12	30.0

Table A.4 Pearson’s chi-square results showing differences between the private HFCV adopters who bought and leased HFCVs.

Variable	N	df	chi-square	p-value
Gender	89	1	0.54	0.46
Education	89	1	3.00	0.69
HVs experience	89	1	0.46	0.49
BEV experience	89	1	1.23	0.26

Significance: *p<0.1, **p<0.05, ***p<0.01

Table A.5 T-test results comparing the mean socioeconomic status of the private HFCV adopters who bought and leased HFCVs.

Variable		Group	N	Std. Dev	Mean	t-ratio	p-value
Socioeconomic status	Household income	Leased	40	4,466,119	10,223,571	0.76	0.44
		Bought	49	4,427,439	9,463,085		
	Age	Leased	40	12.91	61.50	0.52	0.59
		Bought	49	11.74	60.10		
	Household size	Leased	40	1.07	2.62	-0.69	0.48
		Bought	49	1.22	2.80		
	Number of vehicles	Leased	40	0.85	2.20	-1.86	0.06*
		Bought	49	0.91	2.55		

Significance: *p<0.1, **p<0.05, ***p<0.01

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