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Article

Determining the Spanish Public's Intention to Adopt Hydrogen Fuel-Cell Vehicles

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Abstract

Understanding what people think about hydrogen energy and how this influences their acceptance of the associated technology is a critical area of research. The public's willingness to adopt practical applications of hydrogen energy, such as hydrogen fuel-cell vehicles (HFCVs), is a key factor in their deployment. To analyse the direct and indirect effects of key attitudinal variables that could influence the intention to use HFCVs in Spain, an online questionnaire was administered to a representative sample of the Spanish population (N = 1000). A path analysis Structural Equation Model (SEM) was applied to determine the effect of different attitudinal variables. A high intention to adopt HFCVs in Spain was found (3.8 out of 5), assuming their wider availability in the future. The path analysis results indicated that general acceptance of hydrogen technology and perception of its benefits had the greatest effect on the public's intention to adopt HFCVs. Regarding indirect effects, the role of trust in hydrogen technology was notable, having significant mediating effects not only through general acceptance of hydrogen energy and local acceptance of hydrogen refuelling stations (HRS), but also through positive and negative emotions and benefits perception. The findings will assist in focusing the future hydrogen communication strategies of both the government and the private (business) sector.

Keywords: hydrogen fuel-cell vehicles; technology adoption; intention to adopt; survey; Structural Equation Model

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1. Introduction

The interest in hydrogen and fuel-cell technologies stems from the urgent need to decarbonise energy systems. Recent studies highlight hydrogen's expanding role in this transition—from industrial applications to enabling regional shifts in energy systems [1–3]. According to Wallington et al. [4], hydrogen holds promise in the mobility sector, especially in areas where electrification is less feasible, such as long-distance rail, heavy-duty transport, deep-sea shipping, and aviation [2]. Importantly, the social dimension is gaining increased attention, with growing recognition that public acceptance is a critical factor in the successful deployment and integration of green hydrogen technologies [5].

Aligned with this global momentum, the Renewable Hydrogen Roadmap [6] sets out Spain's vision for 2030 and 2050, establishing ambitious goals and outlining key milestones across the industrial, mobility, and electricity sectors. While Spain is emerging as a leading producer of green hydrogen, capitalising on its abundant renewable resources, it remains in the early phases of industrial-scale adoption [7]. Additionally, beyond the crucial role of public and private investments, societal factors are essential for enabling this transition. Bade et al. [8] identify key gaps in the social acceptance of green hydrogen, including limited research on public attitudes, low familiarity, weak stakeholder engagement, and poor integration of social factors into policy and project planning. These issues hinder trust, legitimacy, and long-term viability, and can also be extrapolated to the Spanish context, where there is a notable lack of social studies, particularly on public acceptance and the intention to adopt hydrogen technologies in transport. Without strong support from local communities and the broader public, even the most promising technologies may face resistance, delays, or limited adoption [8].

This study aims to address existing research gaps by analysing the direct and indirect effects of key attitudinal variables that could influence the intention to adopt hydrogen fuel-cell vehicles (HFCVs). By focusing on these psychological drivers within the specific context of Spain—where such analyses are notably limited—it contributes valuable insights into public acceptance and supports a deeper understanding of the factors shaping hydrogen mobility adoption. The research follows a quantitative design, using a survey method consistent with previous studies in Spain. A principal contribution of this study is the application of Structural Equation Modelling (SEM), which facilitates a more robust and comprehensive analysis of the underlying relationships among variables. Based on the technology acceptance framework [9], the initial model was empirically adapted to align with the specific objectives of the present research. In contrast to previous studies conducted in the region that employed conventional statistical techniques, this methodological approach yields complementary insights and contributes to the advancement of scientific knowledge regarding the adoption of hydrogen technologies.

2. Literature Review

As a zero-emission fuel, hydrogen is widely regarded as a key energy solution for the 21st century in response to climate change, offering the potential to meet future energy demands. It could reduce environmental impacts and create new energy opportunities for transportation and distributed heating, as well as for energy storage systems [10]. Consequently, many countries are developing strategies for the expansion of their hydrogen economy. According to the International Energy Agency's (IEA) Global Hydrogen Review 2024 [11], a total of 60 national hydrogen energy strategies have been published as of 2024, covering the countries responsible for over 84% of global energy-related CO_2 emissions. Notably, the majority of these new strategies have stemmed from emerging markets and developing economies, with a strong emphasis on meeting energy production targets.

However, as governments and industries scale up hydrogen technologies, understanding the human dimension becomes increasingly vital. Exploring how people's attitudes toward hydrogen energy influence public acceptance is a critical area of research. This knowledge can inform effective policymaking, industry standards, public communication, and the successful implementation of technologies [12,13]. According to Chen et al. [14], the adoption intention is defined as a consumer's conscious willingness to purchase and use hydrogen technologies in the future. Understanding potential consumers' intention to adopt specific hydrogen applications such as HFCVs is a key factor in their successful deployment. Although HFCVs are still in the early stages of development, these vehicles are already available for consumers to purchase or lease in some countries.

Building on this need for deeper insight into user behaviour, a 2024 meta-analysis by Wang et al. [15] reviewed 24 studies examining the main factors influencing consumers' willingness to adopt HFCVs. The review found that higher levels of education, income, and knowledge about HFCVs positively affect adoption intentions. Additional positive influences included greater availability of hydrogen fuel; a dense network of hydrogen refuelling stations (HRSs); environmental awareness; supportive policy incentives; and favourable consumer attitudes. Conversely, the barriers to adoption were a larger household size; high vehicle purchase price; fuel and maintenance costs; and long refuelling times. Among these, the most significant determinants were purchase price, consumer knowledge, refuelling time, infrastructure availability, and government incentives. These findings have highlighted the importance of addressing both economic and attitudinal aspects in support of the successful market introduction of HFCVs.

A study carried out in Denmark, a country with a strong focus on sustainable transportation, examined the factors influencing public acceptance of HFCVs. It highlighted that environmental awareness, the availability of HRSs, positive media coverage, and prior knowledge of and experience with hydrogen technology, all play a significant role in the acceptance of HFCVs [16]. These findings are consistent with broader international trends. For example, a study in Uzbekistan by Veckalne et al. [17] demonstrated that sustainability awareness is a key driver of public support for green technologies. Tarigan and Bayer [18] found an inverse relationship between hydrogen knowledge and public acceptance—individuals with lower levels of knowledge tended to show greater support for hydrogen development. In contrast, Huijts and Van Wee [19] argued that both objective knowledge and subjective (self-perceived) knowledge positively influence the acceptability of hydrogen energy technologies (HET). Expanding on these perspectives, Scovell [13] emphasised that trust in institutions, positive affective responses, perceived benefits, and lower perceived risks are among the most consistent and significant predictors of public acceptance of hydrogen technologies. Similarly, Emmerich et al. [20] highlighted the role of affect as a key driver, showing that emotional responses significantly shape public attitudes toward emerging energy technologies within the German energy transition. Likewise, trust in the technology and its reliability is a critical driver of public acceptance [21].

Adding to this global perspective, a Japanese study by Khan et al. [22] found that early adopters of HFCVs in Japan, particularly in the Aichi Prefecture, are typically older males with higher socioeconomic status and a strong interest in new technologies. While companies like Toyota and Honda continue to invest in hydrogen technology, widespread consumer adoption remains cautious due to infrastructure limitations, high costs, and uncertainty about the long-term viability of hydrogen-powered vehicles. The study underscored the need for improved infrastructure, clearer policy support, and stronger alignment between industry and consumer expectations to advance hydrogen-based mobility solutions in Japan.

Similarly, India provides another emerging case study in the integration of hydrogen fuel-cell technology into the transportation sector. As part of its decarbonisation strategy, India is actively exploring the deployment of HFCVs, with the market projected to grow significantly in the coming years. A study by Harichandan et al. [23] highlighted the importance of attitude in adopting HFCVs, with cost and risk having significant impacts. This research confirmed that motivation and knowledge sharing have a significant effect on attitudes to HFCVs adoption. Government policy must therefore contain a clear vision for cost-effective HFCVs and the associated public messaging. Another recent study by

Dhingra et al. [24] revealed that among six attitudinal variables, four (high initial cost, limited driving range, reliability, and environmental awareness) play a significant role in shaping consumer attitudes. Conversely, technological innovation and perceived long-term cost savings were found to have a lesser effect. The results also revealed that subjective norms, attitude, and perceived behavioural control have a significantly positive effect on the intention to adopt HFCVs.

Spain is also taking decisive steps toward establishing itself as a leader in the green hydrogen transition. The Spanish Government's Renewable Hydrogen Roadmap (2020) sets ambitious targets for 2030, including 4 GW of electrolyser capacity and key milestones across industry, mobility, and energy sectors [6]. This Hydrogen Roadmap identifies the challenges and opportunities for the development of renewable hydrogen in Spain, providing a series of measures aimed at boosting investment action and taking advantage of the European consensus on the role that this energy vector should play in the context of green recovery. According to the Ministry for Ecological Transition and Demographic Challenge, Spain is actively developing its hydrogen economy through a comprehensive national strategy backed by significant investment. The Spanish government has allocated EUR 794 million to seven major green hydrogen projects across various regions, aiming to add 652 MW of electrolysis capacity and mobilise over EUR 6 billion in investment. Regional initiatives, such as the HyVal project in Valencia, aim to produce 30,000 tons of green hydrogen annually with EUR 2 billion in funding. In addition, Spain is collaborating internationally, including with China, to further boost its green hydrogen capabilities. These efforts position Spain as a key player in the global transition to hydrogen energy [25].

However, despite this growing institutional commitment, empirical research on public attitudes and the social acceptance of hydrogen technologies remains notably scarce in the Spanish context. This gap in the literature underscores the need for more context-specific studies to ensure the success and legitimacy of hydrogen adoption. Societal attitudes towards the potential role of hydrogen in transportation were first assessed in 2016. It was found that Spanish participants were willing to accept hydrogen as a key energy source within the energy and transport sectors [26]. A broader survey across several European countries indicated that, while the public in seven countries (including Spain) showed very low levels of familiarity with hydrogen applications, their attitudes were generally positive, and there was a willingness to accept and support the adoption of residential fuel cells and HFCVs. The study identified significant associations between the acceptance of HFC applications and factors such as positive and negative affect, perceived benefits, preference for alternative technologies, trust, and age [27]. These attitudes were characterised by low levels of strength and stability, highlighting the importance of tracking social acceptance as the technology and its applications develop over time [28]. A recent study in Spain has shown that trust in hydrogen, benefits perception, subjective knowledge, and positive and negative affect are significant predictors of general hydrogen technology acceptance and local acceptance of HRS, but that environmental attitudes, objective knowledge, and age are only significant when considering general acceptance. Moreover, acceptance was found to be marginally lower locally than generally, highlighting the need to study different dimensions of the acceptance of new energy sources [29].

Building on prior research, the present study aims to evaluate the direct and indirect effects of key attitudinal variables (Table 1) on the intention to adopt HFCVs through the application of SEM and contribute to filling the research gap, offering guidance for policy and communication strategies.

Table 1. Definitions for the explanatory variables included in the study.

Dimension	Definition	Studies
Objective knowledge	Factual, verifiable information a person possesses about a topic.	[14,19,30]
Subjective knowledge	Perceived knowledge about hydrogen energy technologies. A person's self-assessed perception of their knowledge; not necessarily accurate.	[18,19,30]
Environmental consciousness	Awareness and understanding of environmental issues, combined with values that prioritise sustainability and pro-environmental behaviour.	[17,24,31]
Trust in hydrogen technologies	Confidence in institutions, experts, or stakeholders responsible for managing and communicating about hydrogen technologies.	[27,29,32]
Positive affect	Emotional responses to hydrogen technologies; positive affect includes enthusiasm and hope.	[20,27,29]
Negative affect	Emotional responses to hydrogen technologies; negative affect includes fear and mistrust.	[20,27,29]
Benefit perceptions	Perceived advantages of hydrogen technologies, such as environmental benefits, energy security, economic opportunity, and innovation.	[13,27,29]
Risk perceptions	Perceived dangers of hydrogen technologies, such as safety concerns, technological uncertainty, high costs, and environmental trade-offs.	[13,27,29]
General hydrogen acceptance	Multi-dimensional evaluation of whether the public supports or rejects hydrogen technology.	[27,29,33]
Local acceptance of HRS	Acceptance of hydrogen technologies by residents and stakeholders in the vicinity of project implementation.	[20,29,34]

3. Materials and Methods

Data was collected through an online questionnaire conducted in December 2022. The sample size of 1000 was based on quota sampling according to gender and age, but geographical distribution and education level were also considered in order to ensure an overall approximation of the general Spanish population. Each respondent received a personalised email invitation and was provided with a unique identifier linked to a single-use access system, thereby ensuring that duplicate entries were not possible.

The questionnaire was designed ad hoc, based on a previous review of the relevant literature [12,13]. It included 40 questions linked to eight attitudinal constructs: environmental consciousness; knowledge about hydrogen (objective and subjective); trust in hydrogen technologies; emotional affect towards hydrogen (both positive and negative); and perception of risks and benefits, plus nine items measuring two acceptance constructs: general acceptance of hydrogen technologies and local acceptance of HRS. Two principal component analyses (PCAs) were conducted on the 40 attitudinal items and the nine acceptance items, which yielded 8- and 2-component solutions, respectively. A varimax rotation was then applied to both solutions to improve interpretability. The internal consistency of the items corresponding to each of the 10 constructs ranged from 0.86 to 0.92. Detailed psychometric information about the generation of the 10 constructs can be found in Sala et al. [29].

A further four items were added to the end of the questionnaire to measure intention to adopt HFCVs: "Assuming hydrogen fuel-cell vehicles come into wide use in Spain, at that time, I would be happy to ride in a hydrogen fuel-cell car" (1 = definitely not, to 5 = definitely yes); "I would be happy to ride in a hydrogen fuel-cell bus"; "I would look forward to driving a hydrogen fuel-cell car"; and "I will make a hydrogen fuel-cell car an option for my next car purchase". The item "I would be happy to ride in a hydrogen fuel-cell car" was intended to capture attitudes toward private or individual use of hydrogen vehicles, whereas the item "I would be happy to ride in a hydrogen fuel-cell bus" referred to public or collective use. This distinction aligns with common interpretations in the Spanish context, where "riding in a car" is typically associated with private transport and "riding in a bus" with public transport. The mean value of the four items was calculated and taken as the dependent variable for the present study. The degree of internal consistency of the four items measuring intention to adopt was 0.907.

The sample was composed of 51.9% women and 48.1% men, proportionally distributed across the various age groups. The average age of the participants was 44 years (SD = 13.5), in a range between 18 and 69. Regarding education, 51% of the sample had a university degree. Nearly 60% of households earned between EUR 14,000 and EUR 42,000 per year. Higher and lower income brackets were less common, each representing around 13% of households (Table 2).

Table 2. Demographic profile of the participants (N = 1000).

Variable	Description	%
Gender	Male	48.1
	Female	51.9
Age	18–28	15.2
	29–39	21.7
	40–50	27.1
	51–60	21.8
	>60	14.2
Education level	High school or below	1.4
	Senior high school	12.6
	Secondary technical school	34.8
	Graduate	38.5
	Postgraduate	11.9
	Other	0.8
Household income	<EUR 14,000	13.8
	EUR 14,000–28,000	29.9
	EUR 28,000–42,000	30.1
	EUR 42,000–56,000	13.0
	More than EUR 56,000	13.2

A path analysis Structural Equation Model (SEM) was employed using Stata software v18 to study the main determinants of the intention to adopt an HFCV. The measurement model included direct and indirect effects, and non-null covariances between exogenous variables. The initial model consisted of the 10 determinants of adoption intention presented in Table 1, incorporating direct effects based on the adaptation of the technology acceptance framework outlined in the introduction. Subsequently, the remaining direct and indirect effects were added iteratively, guided by the modification indices. These indices provide statistics on all omitted paths, identifying which path—direct or indirect—should be included to yield the most significant improvement in the overall model goodness-of-fit, until the RMSEA criteria was below the value of 0.08. While our research did not specifically examine the effect of demographic characteristics on the intention to adopt HFCV, demographic characteristics such as gender, age, or education level have been shown to affect EV purchase intention [23,24] and so were analysed as adjustment variables in the model.

Maximum likelihood and observed information matrices were used for standard errors in the SEM estimation, as the normality of the implied measures had previously been checked. The overall assessment of the model's goodness-of-fit was based on the *p*-value of the model, the Comparative Fit Index (CFI), the Tucker–Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardised Root Mean Square Residual (SRMR) indicators. According to Suhr [35] and Taylor et al. [36], CFI and TLI values greater than 0.9, and RMSEA and SRMR values lower than 0.08, indicate an acceptable fit. Indirect effects were obtained using the product of the involved coefficients, and they were tested and interpreted even where the direct effect was low or insignificant.

4. Results

4.1. Descriptive Analysis

Figure 1 shows boxplots for the 10 determinants and for the intention to adopt. Overall, a moderate to low level of awareness of HFCVs was found. Only 19% of the sample reported high or extreme levels of knowledge about HFCVs, while 23% declared a moderate level. Participants had a high level of environmental consciousness (M = 4.02 in a range from 1 to 5, SD = 0.91) and a medium-high level of trust in hydrogen technology (M = 3.56, SD = 0.79). Benefits from hydrogen (M = 3.95, SD = 0.84) were perceived to be higher than risks (M = 2.75, SD = 0.81). In their general reaction to hydrogen, respondents felt more positive emotions such as joy, hope, or pride (M = 3.50, SD = 1.09) than negative ones such as worry, fear, stress, or anger (M = 2.14, SD = 1.07).

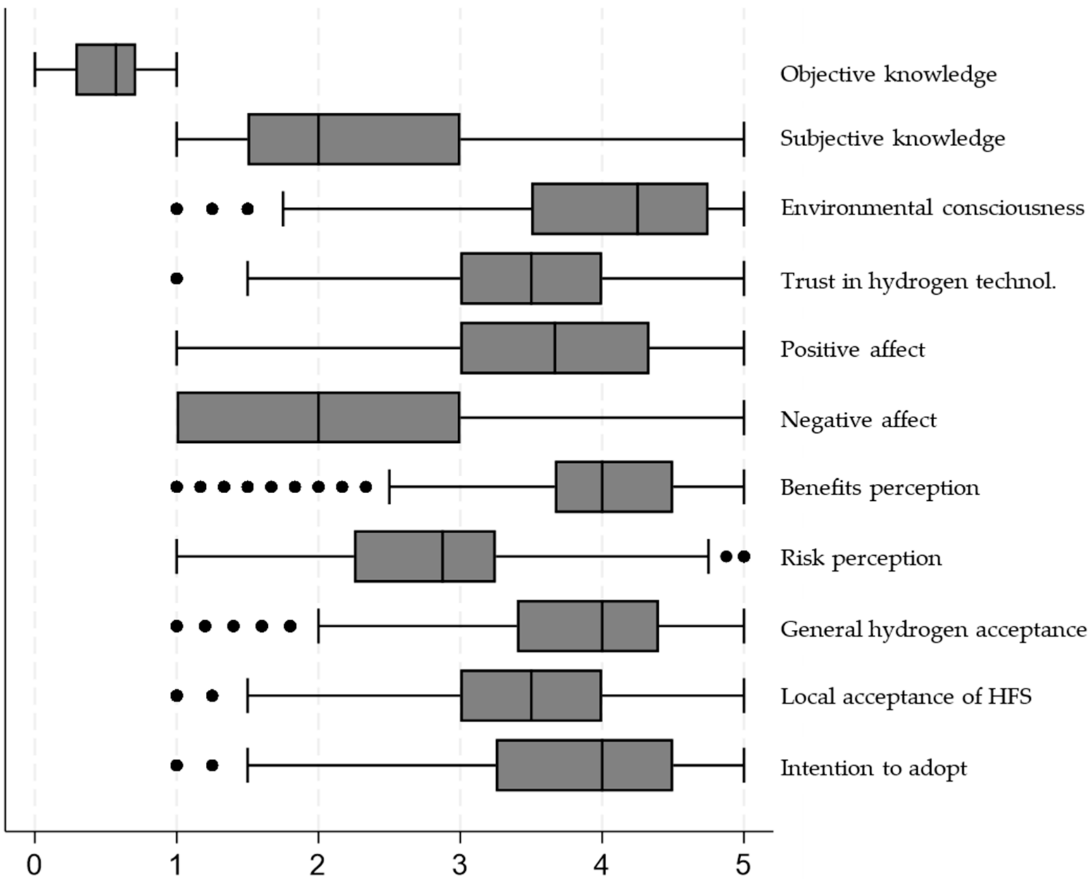

Figure 1. Boxplot of intention to adopt and the 10 measures analysed as its determinants.

Regarding the intention to adopt HFCVs, most of the participants (70%) reported being probably or definitely happy to ride in an HFCV in the future. Likewise, most of the participants (71%) reported that they would probably or definitely be happy to ride in a hydrogen fuel-cell bus. Similarly, 69% of the participants reported looking forward to driving an HFCV, and 63% said they would consider an HFCV as an option for their next car purchase, assuming they come into wide use in Spain. Thus, in general, a high intention to adopt HFCVs in Spain was found, assuming their wider use in the future (an average of 3.8 on a scale from 1 to 5, SD = 0.88). The rate of people reporting no intention to adopt was very low (less than 10%), while around 20% of the participants were undecided.

4.2. Path Analysis

In order to study the main psychosocial determinants of the intention to adopt an HFCV, a theoretical model was drawn up based on the previous relevant literature on the topic. As shown in Figure 2, the theoretical model was tested by means of SEM. The goodness-of-fit of the model was high (CFI = 0.983, TLI = 0.915, SRMR = 0.021, RMSEA = 0.079, with 90% CI = 0.062 to 0.096). Including gender, age, and household income as covariates did not enhance the model's fit, nor did it significantly alter the standardised coefficient; therefore, these variables were excluded from the final path model.

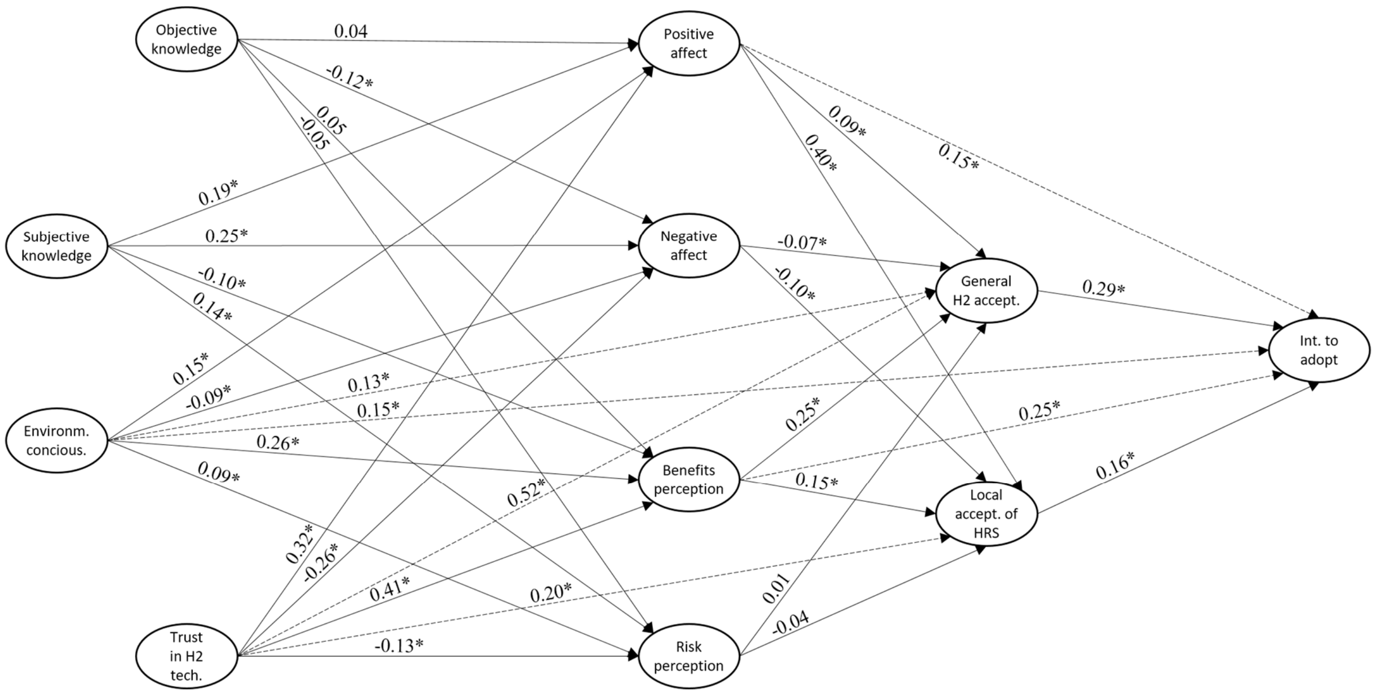

Figure 2. Path analysis of the intention to adopt HFCVs (standardised coefficients, * indicates a p-value < 0.05).

The path analysis results indicated that general hydrogen technology acceptance (β = 0.287) and benefits perception (β = 0.250) have the greatest and most statistically significant (both $p < 0.001$) positive effect on the intention to adopt HFCVs. Moreover, positive emotions (β = 0.146), local acceptance of HRS (β = 0.156), and environmental consciousness (β = 0.148) were found to have a low but significantly positive effect on intended HFCV use ($p < 0.001$). Regarding indirect effects, the key role of trust in hydrogen technology is noteworthy (β = 0.404, $p < 0.001$), having a significant mediating effect not only through general acceptance of hydrogen and local acceptance of HRS but also through positive and negative emotions and benefits perception (Table 3).

Table 3. Predicting intention to adopt HFCV through direct and indirect effects.

Intention to Adopt	Direct Effect	Indirect Effect	Total Effect
Objective knowledge	0	0.031 *	0.031 *
Subjective knowledge	0	0.001	0.001
Environmental consciousness	0.148 *	0.166 *	0.314 *
Trust in hydrogen technologies	0	0.404 *	0.404 *
Positive affect	0.147 *	0.088 *	0.235 *
Negative affect	0	−0.035 *	−0.035 *
Benefits perception	0.250 *	0.094 *	0.344 *
Risk perception	0	−0.004	−0.004
General hydrogen acceptance	0.287 *	NA	0.287 *
Local acceptance of HRS	0.156 *	NA	0.156 *

* Statistically significant ($p < 0.001$); NA: Not applicable.

5. Discussion

The results of this study provided several new insights regarding the intention to adopt HFCVs in Spain. It was found that the intention to adopt HFCVs among the Spanish population was quite high, principally determined by trust in the technology and benefits perception, but with environmental consciousness and positive emotions also playing a role. In addition, general acceptance of hydrogen technologies and local acceptance of HRS should be considered when assessing the intention to adopt an HFCV. In contrast, perceived risks related to hydrogen production, transport, storage, or dispensing had no significant influence on the intention to adopt, while both objective and subjective knowledge of the technology had minimal effect.

5.1. Comparison with Previous Research

The present study showed that 23% of the population are moderately, quite a bit (14%), or extremely (6%) knowledgeable about HFCVs. These findings exhibited some degree of consistency with those reported by the Clean Hydrogen Partnership in 2023 [37], wherein two in ten Spanish respondents indicated that they considered themselves to be somewhat familiar with hydrogen technologies. This convergence reinforced the notion that, while overall familiarity with hydrogen remains limited within the general population, a meaningful proportion of individuals possess some level of awareness. Such emerging awareness was considered likely to play a crucial role in shaping attitudes toward the future adoption of hydrogen-based applications.

In contrast to the findings reported by the Clean Hydrogen Partnership, where fewer than one in ten respondents (7%) in Spain indicated they were likely to switch to a car using hydrogen, our study revealed a substantially higher willingness to adopt HFCVs. This discrepancy can probably be attributed to differences in the design of the questionnaires: while the Clean Hydrogen Partnership survey offered respondents alternative options, such as hybrid vehicles or battery electric vehicles, our study focused specifically on the evaluation of HFCVs, potentially increasing the reported intention to adopt. Differences could also be attributed to the fact that choices were projected into a future where the wider general use of HFCVs was assumed. Additionally, both studies showed that hydrogen is generally perceived as a safe energy source.

The studies by Oltra et al. [27] and Iribarren et al. [26] in Spain agreed that, while familiarity with HFCVs was limited, there was a positive attitude toward their adoption. However, intention to purchase was conditioned by factors such as cost, infrastructure availability, and perceived benefits. Recent research, such as the review by Steller et al. [38] and the study by Huan et al. [39], both from 2024, has confirmed the significant influence of perceived benefits. The present study also posited the key role of benefits perception when studying the intention to adopt HFCVs. These findings suggested that, to encourage the adoption of HFCVs, it is essential to implement public policies that emphasise the benefits and promote greater understanding of these technologies. Likewise, it was found that effective communication and educational strategies could enhance acceptance and foster their implementation in the transportation sector.

The present study highlights the importance of emotion in the adoption of HFCVs. Likewise, the study conducted by Higueras-Castillo et al. [40] in Spain has provided valuable insights into the role of this factor in influencing the adoption of electric and hybrid vehicles (EMVs). Their research emphasised the significant role of emotional factors in shaping consumer attitudes and intentions toward purchasing EMVs. The findings revealed that emotional aspects, such as the enjoyment derived from driving and the perceived pleasure associated with EMVs, have a considerable influence on consumer attitudes. In turn, these positive attitudes lead to a higher likelihood of adopting EMVs. This research underscored the importance of integrating emotional considerations into EMV marketing strategies. By highlighting the pleasurable aspects of driving EMVs or HFCVs and promoting the emotional benefits associated with their use, manufacturers and policymakers could enhance consumer engagement and foster a more favourable climate for adoption. Thus, an emphasis on emotional appeal, alongside technical and economic advantages, could be a key driver in increasing the adoption rate of alternative vehicles in Spain.

The study's findings are somewhat in line with recent studies in other countries that have used SEM to examine the intention to adopt HFCVs or other hydrogen applications. For instance, the study by Gordon et al. in 2024 [41], regarding social acceptance of domestic hydrogen in the UK, identified the importance of trust dynamics and emotions in shaping consumer perceptions. However, their article also highlighted the importance of risk perception, which is not the case in the present study. The 2024 study by Liu et al. [42] of the public's acceptance of new energy vehicles in the Xinjiang Uygur Autonomous Region of China consistently reported a positive correlation between the public's awareness of environmental protection and their attitude toward, and potential acceptance of, new energy vehicles. Dhingra's 2025 study [24] also indicated that environmental awareness significantly influences consumers' attitudes. The government should therefore intensify its environmental protection efforts to enhance public awareness of environmental issues and encourage the green and low-carbon labelling of new energy vehicles.

5.2. Limitations

One of the key limitations of this cross-sectional study using an online survey lay in its inherent inability to capture changes over time. As a snapshot of public opinion at a specific moment, the present study could not account for evolving factors such as advancements in technology, changes in government policies, or shifts in societal attitudes toward HFCVs, which do not appear to have taken place since the data collection of the present study and the time of publication. Furthermore, while the study assumed a broader adoption of HFCVs than currently exists, this assumption may not reflect real-world dynamics, as the actual adoption of new technologies is often influenced by complex, multifaceted factors that may not be fully captured in a one-time survey. Additionally, reliance on self-reported intentions could have introduced biases, as participants may have overstated or misrepresented their future behaviours due to social conformity or lack of factual knowledge about HFCVs. It should also be noted that our sample demonstrates a modest overrepresentation of participants with university-level education. This overrepresentation may be attributable to a minor self-selection bias, potentially linked to the online nature of the survey, which tends to attract individuals with higher levels of education. Lastly, the study's online format may have limited the participation of certain demographic groups, particularly older adults or individuals from lower socioeconomic backgrounds, who may not have had equal access to, or familiarity with, digital platforms, potentially leading to a sample that did not fully represent the diversity of the population.

5.3. Future Research Directions

Future research could include longitudinal studies to track shifts in public opinion and adoption behaviours over time, providing a more comprehensive understanding of how attitudes toward HFCVs evolve alongside technological and market developments. Moreover, qualitative research methods, such as in-depth interviews or focus groups, could provide richer insights into the underlying motivations and barriers influencing consumers' intentions. Further studies might also examine the role of localised factors, such as regional policies, infrastructure availability, and cultural aspects, in shaping the adoption of HFCVs. Additionally, future research should aim to address potential sampling biases by incorporating diverse data collection methods, including offline surveys or community-based approaches, to ensure that the perspectives of all demographic groups are adequately represented.

6. Conclusions

The key determinants influencing the intention to adopt HFCVs in Spain are primarily trust in the technology and perceived benefits. Additionally, environmental awareness and positive emotional responses also play a significant role in this decision-making process. The findings of the present study emphasise the importance of general and local acceptance in the adoption of HFCVs. Achieving large-scale deployment of HFCVs—an objective that inherently depends on broad public uptake—requires addressing not only economic and infrastructural challenges, but also the pivotal role of public acceptance. The transition toward a hydrogen-based transport system will depend substantially on public support, particularly in relation to the development and expansion of hydrogen refuelling infrastructure.

Within the political implications of this study, it is important to highlight the significance of community engagement in the decision-making processes surrounding the siting and installation of hydrogen facilities as an essential factor to fostering a sense of ownership and trust. Strengthening public confidence in hydrogen technologies is key to overcoming scepticism and resistance, and this can be facilitated through targeted information campaigns, transparent communication about safety standards, and clear demonstration of the environmental and social benefits of HFCVs—especially their potential to reduce carbon emissions and contribute to sustainable mobility. Public acceptance extends beyond mere technological familiarity; it also involves addressing deeper concerns related to safety, reliability, and long-term viability.

Specifically, the adoption of HFCVs should not be viewed solely as a technical endeavour, but also as a societal challenge. Strategies that integrate both the rational benefits of hydrogen technologies and the emotional or psychological dimensions of public perception are likely to be more effective in generating broad-based support. Therefore, fostering public engagement and building trust are indispensable components of any successful approach to promoting hydrogen mobility. While attitudes toward hydrogen-based applications are generally positive, a significant challenge remains due to limited public familiarity. Enhancing public acceptance and adoption of HFCVs will therefore require a combination of effective communication strategies, educational efforts, and supportive policy measures aimed at addressing current perceptions and anticipating future concerns.

Our findings offer practical insights for policymakers and stakeholders by identifying the factors that influence the acceptance of HFCVs and highlighting the importance of engaging local communities. These contributions help bridge the gap between technological development and societal readiness and can inform the design of more effective awareness campaigns, participatory planning strategies, and policy measures to facilitate the transition toward hydrogen-based mobility.

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Abbreviations

The following abbreviations are used in this manuscript:

HRSs	Hydrogen Refuelling Stations
HFCVs	Hydrogen Fuel-cell Vehicles
SEM	Structural Equation Modelling
EMVs	Electric and Hybrid Vehicles

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